Curtin School of Allied Health (Physiotherapy)

Low Back Pain, Movement, and Posture. How do They Relate?

A mixed methods investigation into the within-person relationship between movement, posture, psychological factors, and low back pain over time.

Kevin Wernli

ORCID ID: 0000-0001-6035-9873

This thesis is presented for the Degree of
Doctor of Philosophy
of
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Author's Declaration

I declare that this thesis is my own account of my research and contains as its main content work which has not previously been submitted for a degree at any tertiary education institution. To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

Human Ethics: The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research study received human research ethics approval from the Curtin Human Research Ethics Committee (approval number: HRE2017-0706).

[Kevin Wernli]

Statement of Contributors

The candidate, Kevin Wernli, was responsible for all aspects of the research presented in this thesis, including acquisition of funding (PRF Grant No: PG17-004), study design, ethics approval, data analysis, interpretation, reporting of results, and the process of submitting manuscripts.

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Kevin Wernli - August 2021

I, as co-author, endorse that this level of contribution indicated by the candidate above is appropriate.

_______________ Associate Professor Peter Kent (Co-author 1) - August 2021

_______________ Professor Peter O'Sullivan (Co-author 2) - August 2021

_______________ Professor Anne Smith (Co-author 3) - August 2021

_______________ Associate Professor Amity Campbell (Co-author 4) - August 2021

_______________ Mr Jay-Shian Tan (Co-author 5) - August 2021

_______________ Ms Fiona Coll (Co-author 6) - August 2021

Abstract

Introduction

Persistent, non-specific low back pain (LBP) is an escalating and costly problem, consistently reported as the most disabling health condition worldwide. It is influenced by numerous biopsychosocial factors that vary between and within people over time. Movement and posture are two factors commonly believed to be important when it comes to LBP.

Beliefs that 'careful' movement, 'proper' lifting technique and 'good' posture are required to protect or heal the back are commonplace among society. These views are reinforced by clinicians and reflect the almost ubiquitous belief of a relationship between movement, posture, pain, and activity limitation. Cross-sectionally, people with LBP appear to embody this belief, demonstrating, on average, less spinal range of motion (ROM), slower movement, and increased trunk muscle activity during provocative tasks compared to people without LBP. But what happens to movement and posture as LBP changes or improves, and how people with LBP conceptualise this, remains largely unknown.

Current evidence suggests that important movement and postural parameters differ between people with LBP, and that relationships between movement, posture, and LBP may be 'washed out' if individualised measures are not considered. Similarly, the broad factors known to influence movement, posture, and LBP, such as psychological factors (pain-related cognitions and emotions) are also known to vary between those with LBP. As such, LBP is recognized as a heterogenous condition with several multidimensional contributing factors.

Individual-level methods that can accommodate the heterogeneity of LBP provide a viable solution to better understand how movement and posture relate to LBP over time. Further, in-depth qualitative interviews before and after rehabilitation can help garner a richer and deeper understanding of how people with LBP *conceptualise* the movement, posture, and LBP relationship compared to quantitative measures alone.

Therefore, this doctoral thesis aimed to systematically review the; a) cohort study and randomised controlled trial (RCT), and b) single-case design literature investigating how frequently within-person changes in spinal movement relate to

changes in pain or activity limitation, including the type of movement change as LBP improves, c) Investigate the relationship between changes in individually relevant spinal movement and posture, and changes in pain or activity limitation using a replicated, repeated measures single-case series of 12 people with persistent, disabling LBP undergoing a 12-week Cognitive Functional Therapy (CFT) intervention, and d) understand how 12 people with persistent, disabling LBP *conceptualise* relationships between movement, posture, psychological factors, pain, and activity limitation before and after a CFT intervention, and how quantitative changes in these factors integrate with this conceptualisation.

Methods, Results & Discussion

Study 1 - Systematic review: Cohort studies and RCTs

Aim: Determine whether there is a relationship between changes in movement and changes in pain or activity limitation at the individual-level in the cohort study and RCT literature. *Methods:* A prospectively registered (PROSPERO CRD42017064436) systematic review reported using the PRISMA statement guidelines. *Search:* Two reviewers searched four electronic databases for peer-reviewed articles published from inception to January 2020. *Inclusion:* Cohort studies and RCTs of the relationship between volitional spinal movement changes and changes in either pain or activity limitation in people with non-specific LBP. *Selection:* Two reviewers independently examined titles, abstracts, and full texts using Covidence. *Outcomes:* The presence of a relationship between movement changes and pain or activity limitation changes and movement change direction. Q*uality:* An adapted Joanna Briggs Institute Risk of Bias tool assessed each study's methodological quality, while the Grading of Recommendations, Assessment, Development and Evaluations (GRADE) tool was used to assess the overall quality of evidence. *Data analysis:* Descriptively synthesise the frequency changes in movement relate to changes in pain or activity limitation at the individual person level and identify the direction movement changes in the presence of a relationship.

Results: Low-quality evidence from 27 studies involving 2,739 participants identified an individual-level relationship between change in movement and change in pain or activity limitation 31% of the time (20 of the 65 times investigated within the 27 studies). When related, consistently (93% or 18.5 out of 20 relationships observed) spinal ROM increased, movement became faster, and muscle activity reduced (more flexion-relaxation) as pain or activity limitation improved.

Discussion: We infrequently identified a relationship between changes in movement and changes in pain or activity limitation among cohort studies and RCTs. However, limited high-quality evidence with assessor blinding and an ability to accommodate the heterogeneity of LBP precludes a more comprehensive understanding of this relationship. The findings suggest that for many, changes in movement may not be related to improved LBP, they may not have a 'movement impairment' amenable to change, the movement measured may not have been problematic for them in the first place, or changes in psychological (or other unmeasured) factors relate more strongly to pain and activity limitation improvement than changes in movement. In the presence of a relationship, consistently faster, greater amplitude, and more relaxed spinal movement accompanying pain and activity limitation improvement suggests a return toward 'less protective', more normal movement.

Study 2 - Systematic review: single-case designs

Aim: Determine whether there is a relationship between changes in movement and changes in pain or activity limitation at the individual-level in the single-case design literature. *Methods:* Concurrently to study 1, we conducted another systematic review that helped address some of the limitations of study 1. The methods were almost identical, but instead of cohort studies and RCTs, we searched only the single-case literature. This design is more readily able to accommodate between-person heterogeneity, both in the assessment of movement and in the intervention.

Results: The systematic review identified low-quality evidence from 23 relevant studies involving 33 participants. A relationship between changes in movement and changes in pain or activity limitation was identified 68% of the time (58 out of 84 times investigated). Spinal movement range, velocity, and flexion-relaxation consistently (97% or 56 out of 58 relationships) increased as pain or activity limitation improved.

Discussion: Amongst study designs that can readily accommodate the heterogeneity of LBP by individualising the intervention and the assessment of movement, changes in movement *frequently* related to changes in pain or activity limitation. Limited high-quality evidence from studies with assessor blinding, collecting repeated and precise measures of individually relevant movement, pain, and activity limitation, using appropriate statistical analysis, and of patients receiving individualised biopsychosocial interventions still precludes a clear understanding of this relationship.

Study 3 - Single-case series

Aim: Investigate the relationship between changes in individually relevant movement and posture, and changes in pain or activity limitation in 12 people with persistent, disabling LBP. *Methods:* A replicated, repeated measures, A-B-A' single-case design investigated the relationship between within-person changes in movement, posture, pain, and activity limitation; and how movement or posture changes when clinical outcome improves. *Phases:* A (5-week baseline), B (12-week intervention), and A' (5-week follow-up). *Sample:* Twelve adults with persistent, disabling non-specific LBP. *Measures:* Wearable sensors captured individually relevant movements, postures, and muscle activity. Measures were repeated up to 20 times over the 22 weeks, with pain and activity limitation collected concomitantly. *Intervention:* Cognitive Functional Therapy was delivered on up to 10 occasions over the 12-week intervention phase. *Analysis:* A series of cross-correlations adjusting for autocorrelation using Simulation Modelling Analysis provided estimates of the relationships' strength, direction, and significance.

Results: Most participants (10 out of 12) had strong relationships between movement or posture changes and changes in pain and activity limitation, while some showed no strong association. Where relationships were observed, clinical improvement consistently (93%, or 57/61 relationships) related to increased spinal movement range and velocity during bending and lifting, reduced muscle activity (increased flexion-relaxation) during bending, and increased posterior-pelvic-tilt during sitting and standing.

Discussion: In this sample, changes to individually relevant movement and posture frequently related to changes in clinical outcome, but not always. Movement and posture appeared to return towards being 'less protective' when changes were related, but causal directions remain unknown. The specific activities nominated, and the most related movement or postural parameters varied across the participants, highlighting the potential importance of individualised management. Mechanisms and generalisability remain unclear.

Study 4 – Mixed methods

Aim: Understand how 12 people with persistent, disabling LBP *conceptualise* relationships between movement, posture, psychological factors, pain, and activity limitation before and after a CFT intervention, and how quantitative changes in these factors integrate with this conceptualisation. *Methods:* A longitudinal convergent

mixed methods study (run concurrently with study 3). *Sample:* The same 12 adults with persistent, disabling non-specific LBP as study 3. *Measures:* Qualitative interviews and quantitative measures of movement, posture, pain, activity limitation, and psychological factors (pain-related cognitions and emotions) occurring pre- and post-intervention. *Intervention:* 12-week CFT intervention. *Analysis:* Interpretive description guided the mode of inquiry for the qualitative interviews. The qualitative analysis was supplemented by descriptive comparison of pre-post quantitative measures and integrated with a non-parametric test of difference in ranks of change scores for different qualitative groups.

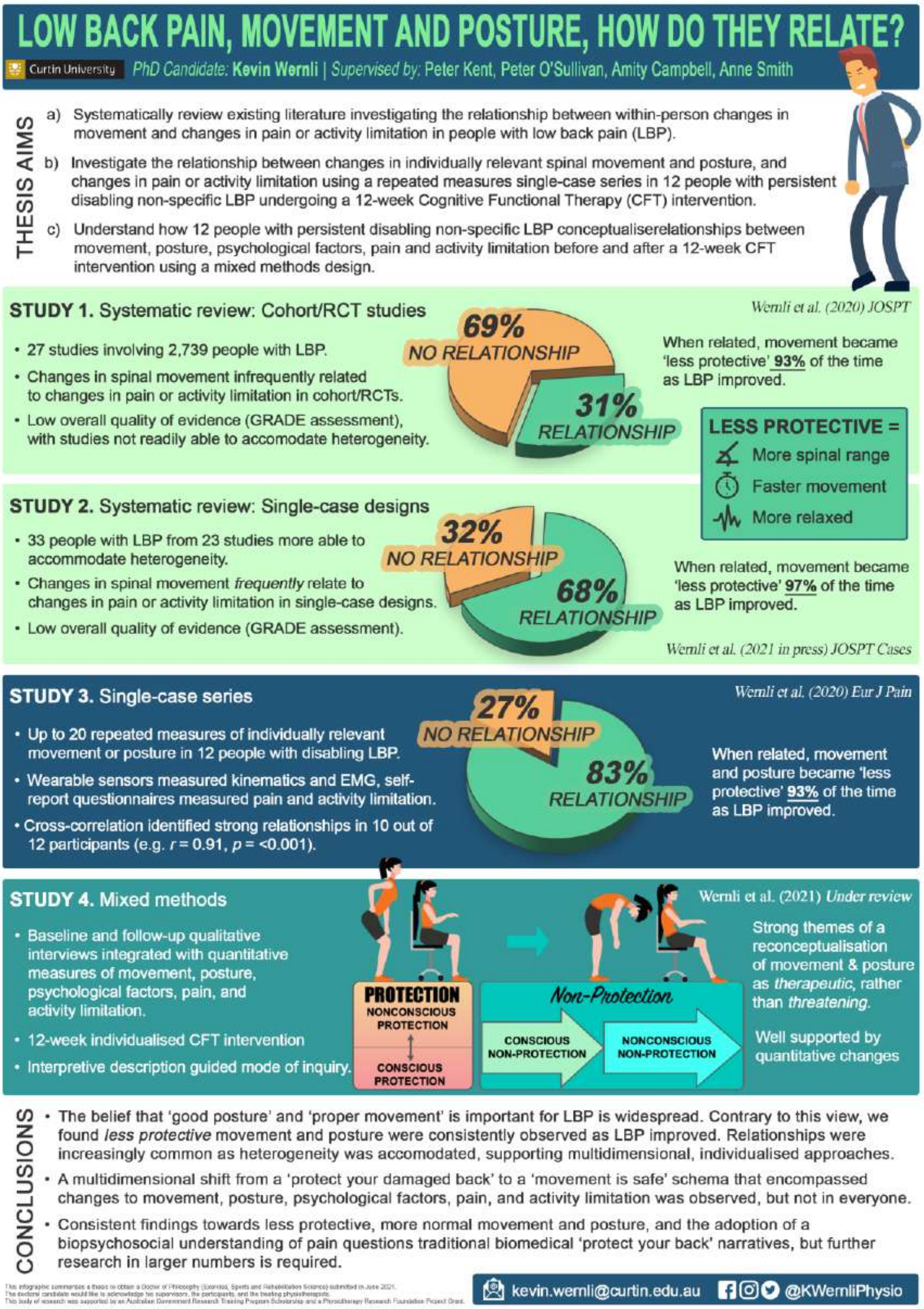
Results: Baseline qualitative interviews garnered clear, consistent themes of 'protection' related to their movement, postural, and damage beliefs - sometimes despite feeling better with less protective, more relaxed patterns. Lived ‘nonconscious’ experiences of stiffness, tension, and restriction were accompanied by ‘conscious’ protective movements and postures embodying fear, caution, and adherence to societal and healthcare conceptual norms. During the follow-up interviews after the CFT intervention, most participants reported how conscious 'non-protective' movement and postural patterns (relaxing, breathing, and moving freely) helped improve their pain, fear, and function, often through experiential learning. Although there was nuance to the journeys, for many participants the new patterns became nonconscious and automatic, where they no longer focussed on their back. The qualitative findings were well supported by quantitative findings of 'less protective' movement, posture, and muscle activity, and changes in pain, activity limitation, and psychological factors, particularly pain self-efficacy and pain catastrophising.

Discussion: Despite participants conveying strong beliefs regarding the need to be 'protective' with their movement and posture during the baseline interviews, at follow-up most reported that being 'less protective' (relaxing and breathing) helped reduce their pain. Regaining confidence doing previously painful, threatening, or avoided tasks, and reducing distress and catastrophising via experiential learning appeared to be important aspects on the journey from protection to non-protection. Gaining control over their condition by implementing strategies to modify movement or posture helped most participants in this sample reconceptualise movement and posture as therapeutic, rather than as a threat.

Conclusion

This doctoral thesis adds knowledge to the current understanding of the relationship between movement, posture, and LBP. Contrary to the limited existing literature, we found that movement and posture changes were *frequently* related to pain and activity limitation changes, when research methods accommodated heterogeneity. In the presence of a relationship, overwhelmingly, movement and posture became 'less protective' as LBP improved, bringing into question common beliefs and recommendations that movement and posture should be protective amongst those with persistent non-specific LBP. Qualitative interviews from 12 people experiencing persistent, disabling LBP revealed a nuanced but common rehabilitative journey. For most, this journey was from nonconscious lived experiences of stiffness and tension accompanied by conscious protective movement and posture, towards consciously relaxed, non-protective, and fearless movement and posture. Many progressed to a point where this non-protective pattern became nonconscious. Most participants appeared to reconceptualise previously provocative movement and posture as therapeutic, rather than as a threat. Future research using larger samples, different interventions, and different designs (such as RCTs) are required to discover how generalisable these findings are and what caused or mediated the changes in movement, posture, pain, and activity limitation observed in this doctoral thesis.

Graphical Abstract



Foreword

In mid 2016, as an inquisitive, inexperienced Physiotherapist who found myself with more questions than answers, I happened to attend a workshop run by Professor Peter O'Sullivan in Queensland, Australia. Little did I know, a series of life-enriching (and, at times, extremely challenging) events lay ahead of me. Pete accepted my haphazard offer for a ride to the airport and the rest, as they say, is history. Next thing you know, I was moving back home to Perth, Western Australia, to embark on this crazy adventure, an adventure that is now (with mixed emotions) drawing to a close.

What really struck me about what I witnessed observing the patient demonstrations during that workshop was how rapidly (within seconds) people's low back pain could change. Often pain that had lasted multiple years or even decades shifted with a few assured tweaks to the persons movement or posture. What I then understood simply as 'certain movements or postures cause pain' and you must 'change them to help improve low back pain', I now understand at a MUCH deeper and more nuanced level. This is thanks to the experiences, curious minds, astute people, skilled clinicians, and brave patients that I have been lucky enough to be exposed to since that fateful workshop.

While researching back pain was never on my horizon, it is a condition that can carry an incredible personal (not to mention, societal) burden. This is something I have witnessed first-hand during high-school, having to call an ambulance for my father because of his severe low back pain – a feeling of helplessness that has no-doubt fuelled motivation (don't worry, he is fine now). I feel utterly privileged to be part of such a distinguished team trying to 'shift the needle' and make a positive difference to the people (and their support team) doing battle with back pain.

Acknowledgements

This thesis represents the cumulative and exponential outcome of many people, processes, sacrifices, and circumstances. I see this as a collective piece of work, rather than an individual undertaking – teamwork makes the dreamwork!

Firstly, to my principal supervisor – the wise, calm, balanced, and fearless leader, **Peter Kent.** My first impression of you was as an incredibly humble, gentle, considered, and *ridiculously* bright individual – an impression that has proved true many times over! Your compassion, generosity, knowledge, and mentorship has been a shining light in my PhD journey, not to mention my personal development. I admire your ability to reflect critically, think deeply, convey clearly, question kindly, and empower liberally. I alluded to the life-enriching experiences in the foreword above… PK, connecting with you has been one of the greatest outcomes of that fateful 2016 'taxi ride' that led to the PhD opportunity, and a friendship I treasure dearly. Thank you for believing in me, challenging me, enabling me, and for being who you are – words truly cannot express my gratitude. I look forward to our journey continuing.

To the charismatic, energetic, positive, genuine, and curious, **Peter O'Sullivan,** my co-supervisor. Wow, what a journey it has been since that taxi ride! If someone had asked me: 'In a utopian world, what does your ideal professional life look like?' a day before your 2016 workshop in Brisbane, I could not have dreamt up a better answer than the position I have found myself in over the last few years – how lucky am I?! What struck me about you was just how much fun you have doing what you're doing – a trait that resonates with me to my core (pun-intended). You've faced health challenges throughout my PhD journey that would easily topple most (twice) yet, in characteristic fashion, have come out stronger and as passionate as ever – a true inspiration to those around you, and a clear example of the values you impart on your lucky patients. We've shared ups, downs, and challenges - and your support/guidance has been respectful and unconditional – thank you! Your ability to see the big picture (with a clarity that is unrivalled), make sense of complex processes, and empower those around you is extraordinary. I am beyond grateful that I get to call you a supervisor, mentor, colleague, mountain-bike-mate, podcast co-host, enabler, and above all, a friend! Here's to the next adventure!

To the considered and grounding super-brains, super-person, super(statistical)model, surfer-girl, **Anne Smith**, my associate supervisor. Never could I imagine that someone with so much humility and knowledge exists! In addition to simply possessing that knowledge, you have a remarkable ability to translate it kindly and generously. Thank you for your commitment to 'epistemology' (one of *many* things I learnt with you). I admire your integrity, honesty, kindness, and humility – thank you for your supervision, mentorship, and friendship. I look forward to drinking wine, surfing waves, and bumping into you at coincidental times along the coastline for many years to come!

To the entertaining, effervescent, efficacious, ever-young, super-mum, **Amity Campbell**, my associate supervisor. Your biomechanical prowess, inquisitive nature, and commitment to fun have been immeasurable positives throughout the past few years. Thank you for always bringing your jovial energy to everything you're involved in, not to mention your analytical excellence. It has been such a pleasure to get to know you (and your family) – it feels much more like a friendship than a supervising relationship, and I love that! I've learnt so much from you and look forward to that learning journey never-ending!

They say you become the average of the people around you, if even a fraction of my supervisory team rubs off on me, then I'm in a really good place! I truly cannot think of a better bunch of supervisors, from a research perspective of course, but more importantly from a human perspective. To my supervisory team, you all epitomise what it is to be a good person and I am eternally grateful to have shared these formative years with you! Thank you for your generosity!

To the great people that happened to be **people with back pain** that participated in the study, thank you for candidly sharing your stories and giving up your valuable time in the pursuit of progress! You made many sacrifices to commit to the demanding data collection schedule (including a 6-hour round trip to Perth almost weekly for half a year for one of you!). I know many of you are off doing great things that you couldn't do before the study… that is fantastic and warms my heart! I cherish the connections I have built because of our time together, and I learnt so much from you as a researcher, clinician, and as a person. May your stories, sacrifices, and successes inspire others with LBP to bravely board the journey back to living!

To my **family**; my parents **Andrea** and **Markus**, twin sister **Jess** (including of course **Jeremy**, **Asha**, and a **little one** yet to arrive), and little sister **Simone**. The opportunities, experiences, and lessons that have come about because of your love have shaped me into who I am today. Thank you for your unconditional care, love, and support.

To the **PhD candidate crew** (aka the 'PHat Docs'). What a unique and memorable (and musical) journey we've been on together. Full of ups, downs, coffee, wine, adventure races, and post-meeting-blues at the lolly wall! Not many people truly understand what a PhD involves, but I feel honoured to share the experience with you lot of legends!

To the treating physiotherapists, **Dr JP Caneiro, Michael Williams, Stacey Cubitt**, and **Rory Kelly.** I'm in awe of your skill and look forward to continuing learning from you. Thank you for your care and patience.

To my **friends**, thank you for your endless support, fun, banter, and encouragement. To the additional co-authors in the papers that form the body of the thesis, **Jay-Shian Tan** and **Fiona Coll**, thank you for your help with some heavy screening and data analysis. To the delightful staff at **Body Logic Physiotherapy**, thank you for accommodating research related re-arrangements. To the Curtin team, including academic, teaching, and admin colleagues (namely **Paul Davey** for your computer program writing proficiency and **Dr Leo Ng** for being the pleasantly persistent PhD plant-seeder). To **Dr Samantha Bunzli**, thank you for your qualitative expertise.

While money isn't everything, I've learnt it does seem to make the world go round. I could not have completed this work without the support from an **Australian Government Research Training Program Scholarship, a Curtin University/School of Physiotherapy and Exercise Science Postgraduate Scholarship**, and a **Physiotherapy Research Foundation Project Grant** from the **Australian Physiotherapy Association.** Thanks also to **Body Logic Physiotherapy** for their in-kind contribution to ensure the projects smooth operation.

Dedication

I acknowledge the fortuitous circumstances that have unfolded ‘behind the scenes’ that bring me to this point in time today. As a 23-year-old white male with Swiss heritage, a tertiary education, and from a middle-class background, I started this PhD from a position of privilege. There are many subconscious privileges and prejudices that have landed in my favour up until this point. We only need to look at health outcomes to get a glimpse into the impact of social inequalities. First nation people across the world often fare significantly worse in almost all ways measured, not to mention other racial, gender, and identity inequalities. The works of this thesis were completed on land stolen from the Whadjuk Noongar people, the traditional custodians of Boorloo, the land we now call Perth, Western Australia. May we continue in the pursuit of equality and fairness.

Without overlooking the work that it took me to get here, I dedicate this thesis to those in less fortunate positions than mine, particularly those who think (or have been told) ‘you can’t’.

List of publications

Published

Wernli, K., Tan, J., O'Sullivan, P., Smith, A., Campbell, A., & Kent, P. (2020). Does movement change when low back pain changes? A systematic review. *Journal of Orthopaedic and Sports Physical Therapy, 50*(12), 664-670. https://doi.org/10.2519/jospt.2020.9635

Wernli, K., O'Sullivan, P., Smith, A., Campbell, A., & Kent, P. (2020). Movement, posture and low back pain. How do they relate? A replicated single-case design in 12 people with persistent, disabling low back pain. *European Journal of Pain, 00*, 1-19. https://doi.org/10.1002/ejp.1631

Accepted

Wernli, K., Tan, J., O'Sullivan, P., Smith, A., Campbell, A., & Kent, P. (2021 (in press)). 'But I'm and Individual' - The relationship between changes in movement and changes in low back pain. A systematic review. *JOSPT Cases*.

List of submitted manuscripts

Wernli, K., O'Sullivan, P., Coll, F., Kent, P., Campbell, A., & Smith, A. (2021). From protection to non-protection: A mixed methods replicated single-case series investigating movement and posture in 12 people with disabling low back pain undergoing Cognitive Functional Therapy.

List of presentations

Oral presentations

Wernli K, O'Sullivan P, Smith A, Campbell A, Kent P. "Movement, posture, and low back pain, how do they relate?" Curtin University Physiotherapy and Exercise Science Emerging Research Conference (online), November 19, 2020

Wernli K, O'Sullivan P, Smith A, Campbell A, Kent P. "Movement, posture, and low back pain, a case report". Mark Liveris Research Student Seminar/3-Minute-Thesis. Curtin University, Perth. September 27, 2018

Wernli K, O'Sullivan P, Smith A, Campbell A, Kent P. "The relationship between movement and pain. Presentation of a single case from an experimental case series of 12 people with disabling low back pain." 'Visualize your Thesis' presented by the University of Melbourne (online). August 18, 2018

Wernli K, O'Sullivan P, Smith A, Campbell A, Kent P. "Low back pain… Does movement and posture matter?" Pitch It Clever (online). Universities Australia. February 2018

Wernli K, O'Sullivan P, Smith A, Campbell A, Kent P**. "**An Investigation of the relationship between movement, posture, and low back pain". Mark Liveris Research Student Seminar/3-Minute-Thesis. Curtin University, Perth. September 28, 2017

Poster presentations

Wernli K, O'Sullivan P, Smith A, Campbell A, Kent P. **"**Does biomechanics matter? How changes in movement and posture relate to changes in pain and activity limitation in 12 people with persistent, disabling low back pain". Research to Practice 2021 (online), May 7, 2021.

Wernli K, O'Sullivan P, Smith A, Campbell A, Kent P. "The relationship between movement, posture, pain, activity limitation and psychological factors: A case report". Research Rumble, Curtin University, March 27, 2019.

Wernli K, O'Sullivan P, Smith A, Campbell A, Kent P. "Movement, posture, psychological factors and low back pain. A case report". NOI Explain Pain 3 at the 'G. Melbourne, Australia. November 8-11, 2018

Wernli K, O'Sullivan P, Smith A, Campbell A, Kent P. "Low back pain, movement and posture. A case report". Mark Liveris Research Student Seminar, September 27, 2018.

Wernli K, O'Sullivan P, Smith A, Campbell A, Kent P. "The Relationship Between Movement, Posture, and Low Back Pain". Mark Liveris Research Student Seminar, September 28, 2017

Co-authored publications

O'Sullivan, P., Caneiro, J. P., Sullivan, K., Lin, I., Bunzli, S., **Wernli, K.**, & O'Keeffe, M. (2019). Back to basics: 10 facts every person should know about back pain. *British Journal of Sports Medicine*. https://doi.org/10.1136/bjsports-2019-101611
In addition to creating the infographic and figure for this publication in collaboration with the authors, I also produced two videos and multiple podcast episodes for this manuscript (see Appendix A.2)

Caneiro, J. P., Roos, E. M., Barton, C. J., Sullivan, K., Kent, P., Lin, I., Choong, P., Crossley, K. M., Hartvigsen, J., Smith, A. J., **Wernli, K.**, & O'Sullivan, P. B. (2020). Infographic. Roadmap to managing a person with musculoskeletal pain irrespective of body region. *British Journal of Sports Medicine, 54*(9), 554. https://doi.org/10.1136/bjsports-2019-101681

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Physiotherapy Research Foundation Project Grant (A$16,820) – Awarded in 2017:
"Does changing movement matter? Understanding the relationship between changes in movement, pain, activity limitation and psychological factors in persistent low back pain". Funded by the Physiotherapy Research Foundation, Australian Physiotherapy Association.
Applicants: **Kevin Wernli**, Peter Kent, Peter O'Sullivan, Amity Campbell, Anne Smith

Prizes and awards

People’s choice award:
Wernli K, O’Sullivan P, Smith A, Campbell A, Kent P. “Movement, posture, and low back pain, how do they relate?” Curtin University Physiotherapy and Exercise Science Emerging Research Conference (online), November 19, 2020

Research commercialisation prize:
Wernli K. Start Something Research Commercialisation Program. Curtin University, Perth. June 26, 2019. (See Appendix B)

Finalist:
Wernli K, O’Sullivan P, Smith A, Campbell A, Kent P. “The relationship between movement, posture, pain, activity limitation and psychological factors: A case report”. Research Rumble, Curtin University, March 27, 2019.

Best poster presentation:
Wernli K, O’Sullivan P, Smith A, Campbell A, Kent P. “The relationship between movement and low back pain: a case report”. Mark Liveris Research Student Seminar, September 27, 2018.

3-Minute Thesis Finalist:
Wernli K, O’Sullivan P, Smith A, Campbell A, Kent P. “The relationship between movement and low back pain: a case report”. 3-Minute-Thesis. Curtin University, Perth. August 31, 2018

Finalist and people’s choice award:
Wernli K, O’Sullivan P, Smith A, Campbell A, Kent P. “The relationship between movement and pain. Presentation of a single case from an experimental case series of 12 people with disabling low back pain.” ‘Visualize your Thesis’, presented by the University of Melbourne (online). August 18, 2018

Best poster presentation:
Wernli K, O’Sullivan P, Smith A, Campbell A, Kent P. “The Relationship Between Movement, Posture, and Low Back Pain”. Mark Liveris Research Student Seminar, September 27, 2017

Professional engagement

Wernli, K. “Lumbar spine movement and low back pain”. Knowledge is our Foundation – Physiotherapy Research Foundation Update Brochure. December 2018

Wernli, K. “Using wearable sensors to investigate how movement and posture relate to low back pain”. InTouch – Musculoskeletal Physiotherapy Australia Magazine. August 2018

Wernli, K. “Young researcher’s unique approach”. InMotion – Australian Physiotherapy Association magazine. May 2018

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List of Abbreviations

BackPAQ	Back Pain Attitudes Questionnaire
CFT	Cognitive Functional Therapy
CI	Confidence Interval
COREQ	COnsolidated criteria for REporting Qualitative research
CSM	Common Sense Model
EMG	Electromyography
FreBAQ	Fremantle Back Awareness Questionnaire
GRADE	Grading of Recommendations, Assessment, Development and Evaluations
LBP	Low back pain
NSLBP	Non-specific low back pain
MCIC	Minimal Clinically Important Change
MDC	Minimal Detectable Change
MRI	Magnetic Resonance Imaging
NRS	Numerical Rating Scale (0-10 unless otherwise stated)
OMPQ	Örebro Musculoskeletal Pain Questionnaire
PCS	Pain Catastrophising Scale
PHODA	Photographs of Daily Activities
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analysis
PROSPERO	International Prospective Register of Systematic Reviews
PSEQ	Pain Self-Efficacy Questionnaire
PSFS	Patient Specific Functional Scale
RCT	Randomised Controlled Trial
RMDQ	Roland Morris Disability Questionnaire
ROM	Range of motion
SCED	Single-Case Experimental Design
SMD	Standardised Mean Difference
TBC	Treatment Based Classification
Tri.NRS	Mean numerical rating scale (0-10) of current, worst, and average pain intensity over the last week
TSK	Tampa Scale of Kinesiophobia

Chapter 1 Introduction

“”Low back pain… an urgent global public health concern” -
– p2357 from Paper 1 from Lancet Low Back Pain Series (Hartvigsen et al., 2018)

Pain is an individual, sensory, and emotional experience influenced by unique and varying combinations of biological, psychological, and social factors (Raja et al., 2020). The concept of pain is learnt through life experiences and a person’s report of pain should always be respected (Raja et al., 2020). It is an experience that is dependent on an evaluation (often nonconscious) of real or potential threat to a person’s health homeostasis, resulting in protective measures in an attempt to restore homeostasis (Moseley & Butler, 2017; Wallwork et al., 2016) (we chose to use the term nonconscious over unconscious as unconscious often refers to being in a state in which a person is unable to respond). These protective measures come in numerous forms; chemical and hormonal in the form of the ‘inflammatory cascade’ (Risbud & Shapiro, 2014); neurological in the form of transmission of (potentially noxious) information along neural pathways (Cavanaugh, 1995); cognitive and emotional in the form of thoughts and feelings in attempt to make sense of, communicate, and reduce future risk (Moseley & Butler, 2015; Rossettini et al., 2020); and behavioural in the form of controlling bodily movements and postures to avoid or lessen the potential for pain and harm (O’Sullivan et al., 2018). In the context of acute tissue trauma and pathology (such as a fracture or a disc herniation with neural compromise), these protective measures are usually helpful, facilitating the healing process. However, in the context of persistent pain that continues beyond traditional tissue healing times or in the absence of tissue damage, the benefit of these protective measures is questioned, and they can be unhelpful, overprotective, and provocative (Moseley & Butler, 2017; O’Sullivan et al., 2016).

Pain in the lower back remains the most disabling health condition worldwide (Buchbinder et al., 2020; Hartvigsen et al., 2018) and results in enormous economic costs (more than cancer and diabetes combined) (Hoy et al., 2014). Yet despite significant effort and funding, the functional and economic burden continues to grow (Buchbinder et al., 2020), with low-income and middle-income countries seeing the starkest increases (Hartvigsen et al., 2018).

In addition to huge societal and economic impacts, low back pain (LBP) can also have a significant impact on the person experiencing it, as well as those around them (Bunzli et al., 2013; Toye et al., 2013). An array of cognitions, emotions, actions, and appraisals occur in a person's attempt to make sense of their condition (Leventhal et al., 2016). The Common Sense Model (CSM), proposed by Leventhal, suggests the representation of illness is influenced by lived experiences, encounters with others such as clinicians, and from environmental cues such as societal or occupational messaging (Leventhal et al., 2016). If the condition resolves promptly, then minimal attention and distress ensues, however, if the experience is prolonged, unpredictable, or frightening, it can become distressing, unpleasant, and disabling (Bunzli, Smith, Schütze, et al., 2015). This is especially the case if it impacts a person's daily functioning, or threatens a person's ability to pursue their valued goals (Moseley & Vlaeyen, 2015; Vlaeyen et al., 2016).

A distressing LBP experience can be intensified if the symptoms are unpredictable or attempts to manage or control the condition fail (Bunzli, Smith, Schütze, et al., 2015). While trajectories vary (Kongsted et al., 2016), most episodes of LBP settle quickly (da C Menezes Costa et al., 2012; Pengel et al., 2003), about three in five people experience a recurrent, fluctuating pattern, and about one in 10 don't recover at all (Kent & Keating, 2005). It is this minority that experience ongoing disabling LBP that account for the majority of the economic and societal costs (Abenhaim & Suissa, 1987; Buchbinder & Underwood, 2012; Kent & Keating, 2005). According to the CSM, in response to a health threat such as LBP, a representation of that threat is developed, including cognitions and emotions related to the threat. Actions and behaviours follow to address and control the threat, and continuous feedback appraises the effect of the actions and the progression of the threat (Leventhal et al., 2016). For LBP, bodily actions that commonly occur include the modification of movements or postures in an effort to protect, or the avoidance of potentially threatening tasks (including painful movements or postures) (O'Sullivan et al., 2016; O'Sullivan et al., 2018; Vlaeyen et al., 2016).

The relevance of movement and posture in lower back pain represents a common topic among people experiencing LBP and their carer's, clinicians that treat LBP, healthcare professional educators, occupational health and safety professionals, fitness professionals, and people without LBP (Caneiro et al., 2018; Hush et al., 2009; Karayannis et al., 2016; Lin et al., 2013; Mitchell et al., 2009; Nolan et al., 2018). For a topic to have such widespread prominence, it is reasonable to expect there to be substantial, high-quality, and uniform evidence informing the relationship between movement, posture, and LBP. Surprisingly, however, evidence supporting this relationship is unclear.

There is some consensus that people with LBP demonstrate more ‘protective’ movement and postural patterns (less spinal range, slower movement, increased muscle guarding) than those without LBP at a single point in time (Geisser et al., 2005; Laird et al., 2014; Laird et al., 2018; Tsang et al., 2017). But how movement and posture *changes* as low back pain improves is less clear, with existing systematic reviews of group-level randomised controlled trials (RCT) suggesting changes in movement are *infrequently* related to changes in pain or activity limitation (Laird et al., 2012; Steiger et al., 2012).

The lack of clear understanding is also reflected by the various different movement- and postural-based treatment approaches for low back pain (Karayannis et al., 2016; Riley et al., 2019). These approaches often advocate quite disparate, sometimes opposing, interventions, yet show similar efficacy (Karayannis et al., 2016; Riley et al., 2019; Smith et al., 2014). This may reflect the heterogenous nature of LBP, where generic movement- or postural-based interventions only show modest efficacy on average because they cannot readily accommodate individual variability. Understanding more about the quantitative relationship between changes in movement, posture, and LBP at an individual level may provide valuable insights into how, in whom, and if, movement and posture should be considered.

Questions about the *quantitative* relationship between changes in movement, posture, and LBP remain a focus among society (including clinicians and researchers). Qualitatively, people experiencing LBP also place ‘proper’ movement and ‘good’ posture in high regard (Darlow et al., 2015; Darlow, Perry, Stanley, et al., 2014). Reports of stiff, tense, braced, restricted, and fearful movements and postures are apparent in people with LBP (Bunzli, Smith, et al., 2016; Bunzli, Smith, Watkins, et al., 2015; Oosterhof et al., 2014; Pugh & Williams, 2014; Snelgrove et al., 2013). When it comes to recovery, there are also indications that moving freely, being supple, and producing more efficient, relaxed, and comfortable movements or postures are important for people with LBP (Hush et al., 2009; Pugh & Williams, 2014). While there is substantial qualitative research into the lived experiences of people with LBP (Bunzli et al., 2013; Toye et al., 2021; Toye et al., 2013), there is little exploring how people with LBP *conceptualise* relationships between movement, posture, psychological factors (pain related cognitions and emotions), and LBP, particularly over time.

In consideration of the current lack of clarity regarding the relationship between movement, posture, and LBP, the body of work presented in this doctoral thesis aims to:

a) Review the current available evidence regarding the relationship between changes in movement and posture, and changes in LBP, with a particular emphasis on investigating individual-level data.

b) Rigorously investigate this relationship using repeated measures of movement, posture, and LBP before, during, and after an intervention.

c) Understand how people with LBP *conceptualise* the relationship between movement, posture, and their LBP before and after rehabilitation. Integrating qualitative findings with quantitative findings of movement, posture, pain, activity limitation, and psychological factors (pain-related cognitions and emotions).

1.1 Thesis structure and notes

This thesis is comprised of seven chapters. Chapters three to six present four manuscripts that have either been published, accepted, or submitted, and therefore have their own appendices (titled 'Chapter Appendices') while Chapter 8 presents appendices for the thesis (titled 'Thesis Appendices'). Below are brief overviews of each chapter.

Chapter 1 introduces the problem of low back pain, the current evidence regarding the relationship between movement, posture, and low back pain, and current gaps in the understanding of this relationship.

Chapter 2 presents a literature review defining LBP, its burden, common beliefs, how movement and posture relate to LBP, the role of psychological factors, current gaps in the movement, posture, and LBP relationship literature, and methodological or technical ways to investigate this relationship.

Chapter 3 provides the findings from a systematic review investigating the relationship between changes in movement and changes in pain or activity limitation among cohort studies and randomised controlled trials (RCTs). This study was published in the *Journal of Orthopaedic & Sports Physical Therapy* and will be presented in its published format.

Chapter 4 provides the findings from a second systematic review investigating the relationship between changes in movement and changes in pain or activity limitation, but this time among the single-case design literature. This study has been accepted for publication in *JOSPT Cases* and will be presented in its accepted format.

Chapter 5 reports the findings from a replicated single-case design. In this original research, relationships between movement, posture, pain, and activity limitation were investigated using up to 20 repeated measures of these factors over 22 weeks. Measures occurred before, during, and after a Cognitive Functional Therapy (CFT) intervention in 12 people with persistent, disabling non-specific LBP. This study was published in the *European Journal of Pain* and will be presented in its published format.

Chapter 6 reports the findings from a mixed-methods study investigating how the 12 people with disabling LBP from the single-case series in Chapter 5 *conceptualised* the relationship between their movement, posture, and LBP. Findings from qualitative interviews conducted before and after the intervention were integrated with baseline and follow-up quantitative measures of movement, posture, pain, activity limitation, and psychological factors. This study has been submitted and will be presented in its submitted format.

Chapter 7 presents a discussion of the main findings of this thesis. The disruption of an embodied 'protect your damaged back' schema is proposed to understand the relationship between movement, posture, and LBP as people with persistent non-specific LBP improve. Implications for people with LBP, clinicians, and society are also discussed. The chapter concludes by describing the strengths and limitations of this body of work and future research directions and finishes with the concluding remarks.

1.1.1 Notes about this thesis

This thesis has been written in accordance with the publication manual of the American Psychological Association, 7th edition (American Psychological Association, 2020). Figure and Table ordering has been optimised for this thesis and may therefore not follow conventional ordering for each individual manuscript.

The PDF version of this thesis contains cross references and clickable links to assist navigation. The table of contents remains active and can be found among all common PDF viewers (for example in the 'Table of Contents' sidebar in Preview for MacOS, or under 'Bookmarks' in Adobe Acrobat).

Chapter 2 Literature review

This chapter aims to review the current scientific literature regarding; a) the definition, burden, and beliefs of low back pain, b) how movement and posture relate to LBP, c) how psychological factors influence movement, posture, and LBP, d) models to understand LBP, e) the current gaps in the movement, posture, and LBP relationship literature, and f) methodological and technical ways to investigate and measure the relationship between movement, posture, and LBP.

2.1 The low back pain landscape

2.1.1 The definition and prevalence of low back pain

Low back pain is defined as pain experienced in the dorsal aspect of the body between the 12^{th} thoracic vertebrae and the gluteal folds (Deyo & Weinstein, 2001; Hartvigsen et al., 2018). It may be accompanied by pain in one or both lower limbs, with or without neurological symptoms (such as altered power, reflexes, or sensation) (Deyo & Weinstein, 2001). It is extremely common, with between 50% and 80% of the world's population experiencing LBP at some stage in their life (Andersson, 1998; Dionne et al., 2008; Freburger et al., 2009; Hartvigsen et al., 2018; Ma et al., 2014; Picavet et al., 1999). In 2021, approximately 590 million people globally experience activity-limiting LBP at any one time based on the point prevalence estimate of 7.3% in 2015 (Vos et al., 2015). Most experiences of LBP are short lived with a systematic review and meta-analysis of 33 cohorts and 11,116 participants providing strong evidence that most episodes improve considerably within 6 weeks, with low pain levels by 12 months (6 points on a 100-point scale; 95% Confidence Interval (CI) [3, 10]) (da C Menezes Costa et al., 2012). Despite this favourable prognosis, recurrence is common (Kongsted et al., 2016). A recent systematic review suggests around 33% will experience a recurrence within one year of recovering from a previous episode, although robust estimates were hampered by a lack of high-quality research (da Silva et al., 2017).

Low back pain is being increasingly understood as a long-term condition with a variable and fluctuating time course rather than a series of unrelated episodes (Dunn et al., 2013). Approximately half of those with LBP seen in primary care experience continuing or fluctuating pain of low to moderate intensity, some recover, and some experience symptoms that persist (Kongsted et al., 2016). The proportion that develops persistent, disabling LBP varies depending on the definitions and time periods used. For example, at three months post presentation to a general practitioner in the Netherlands for acute or persistent LBP, 35% still experienced LBP in the past five weeks (van den Hoogen et al., 1998). Similarly, 39% of people with a new episode of LBP that presented to their general practitioner in northwest England still reported persistent, disabling LBP at three months defined by pain greater than 20mm on a 100mm Visual Analogue Scale (VAS) and a Roland Morris Disability Questionnaire score greater than four (Jones et al., 2006). In contrast, 79% of people with LBP presenting to their general practitioner in south Manchester, England, had not recovered at three months as defined by pain less than two out of 10 (VAS) and disability less than 91% using the Hanover back pain daily activity schedule (100% representing no activity restriction) (Croft et al., 1998). At 12 months follow-up, 75% of people still hadn't recovered in the Croft et al. (1998) study, while only 10% still reported LBP in the van den Hoogen et al. (1998) study.

A meta-analysis of 11 prospective cohort studies in 2013 reported that 67% (95% CI [50%, 83%]) of people will still report some pain at three months following a LBP episode, and 65% (95% CI [54%, 75%]) at 12 months (Itz et al., 2013), results similar to a previous review of 36 studies of LBP among general patient populations (Hestbaek et al., 2003). When considering admissions to emergency departments for LBP, of 600 consecutive patients, 68% (95% CI [64%, 72%]) had completely recovered within 12 months (Oliveira et al., 2021). For 281 people with acute LBP consulting primary care, repeated long term follow-up (up to six, monthly questionnaires from five to seven years follow-up) showed that 20% experienced persistent severe pain (defined as a score greater than four out of 10 using the mean of least and usual pain over the last two weeks, and current pain rated on an 11-point (0-10) numerical rating scale), 46% experienced persistent mild pain, 28% experienced no or occasional mild LBP, and 5% experienced a fluctuating pattern (Chen et al., 2018). Of note, and as is characteristic of studies with long-term follow-up, these results were from only 18% of the original baseline 1,591 participants in this cohort (Chen et al., 2018). While the authors report that the drop-out analyses showed few differences other than that the included participants were slightly older (Chen et al., 2018), the trajectories of the other 1,310 people remain mostly unknown. The variability in estimates of persistent LBP and/or disabling pain at longer term time points partially reflects differences in the definitions used.

In summary, while most people will experience LBP symptoms throughout their life, they usually improve quickly and substantially, even though about two-thirds still report some symptoms at three and twelve months. Ongoing, fluctuating symptoms are common, and approximately 10-20% experience persistent LBP that is disabling or severe (Chen et al., 2018; Kent & Keating, 2005; Kongsted et al., 2016; Schmidt et al., 2007). Notably, these data only relate to people with LBP that seek care and does not represent those who never seek care regardless of severity. A review of 13,486 people from 10 population-based studies identified that 58% (95% CI [32%, 83%]) of people with LBP seek care (Ferreira et al., 2010), highlighting that a substantial percentage of people with LBP don't appear to seek care.

In the empirical studies in this thesis, persistent (or chronic) LBP is defined as pain that lasts longer than three months, traditionally considered to be beyond the time required for natural healing to occur (Deyo & Weinstein, 2001) and disabling LBP refers to a score of greater than four points on the Roland Morris Disability Questionnaire (RMDQ) (Jones et al., 2006; Patrick et al., 1995).

2.1.2 The burden of low back pain

Low back pain remains the most disabling health condition globally, topping the list of causes of disability in 126 of 195 countries and territories in the 2017 Global Burden of Disease Study (Vos et al., 2017). Of concern, LBP-related disability continues to increase despite substantial and sustained efforts to abate its impact (Deyo et al., 2009). In the 25 years since 1990, a 54% increase in LBP related activity limitation (measured in disability-adjusted life-years) has been observed, with the biggest increases observed in lower- and middle-income countries (Hartvigsen et al., 2018). Of note, burden estimates in the Global Burden of Disease Study are heavily reliant on models rather than original data, and substantial heterogeneity remains between the case definitions used among the included studies (James et al., 2018). So, improvements in the models, changes in the disability weights, the construction of a Socio-Demographic Index, and adjustments for comorbidity may influence burden estimates across countries and over time (James et al., 2018; Wu et al., 2020). This makes comparisons and the measurement of the impact of changes to LBP policy and practice difficult (James et al., 2018; Wu et al., 2020). Further, incomplete coverage across countries and time, and limitations in the primary prevalence studies included in the 2017 Global Burden of Disease Study result in considerable uncertainty about prevalence estimates and therefore disease burden metrics derived from these estimates (Tamrakar et al., 2021). Despite this consideration, studies that have used consistent methods also observed increasing prevalence (Freburger et al.,

2009) and economic costs (Deyo et al., 1991), suggesting the burden of LBP is, in fact, increasing.

While prevalent across the lifespan, disability from LBP is highest in those of working age (Australian Institute of Health and Welfare, 2020; Hartvigsen et al., 2018), hindering economic and productivity growth (Buchbinder et al., 2020). In Australia, LBP is the most common health condition forcing early involuntary retirement (Schofield et al., 2008), while in the United States it accounts for more lost workdays than any other musculoskeletal condition (United States Bone and Joint Initiative, 2020). LBP is also the most common cause of sick leave and early retirement in Europe (Bevan et al., 2009).

The disability related to low back pain is also associated with poor quality of life (made up of poor perceived health, very high levels of psychological distress, and likelihood to report very severe body pain) (Australian Institute of Health and Welfare, 2020). A survey of 540 people from New Zealand found that musculoskeletal pain (of which the back and shoulder were the most common sites affected), found that health-related quality of life for people with musculoskeletal pain was comparable to complicated diabetes mellitus, chronic liver disease prior to transplantation, and terminal cancer (Taylor, 2005). Notably, the response rate in that study was lower in Maori people and in those under 40 years of age, limiting generalisability to these populations. These findings, along with the perceived loss of identity, ongoing pain experiences, multiple failed treatments, conflicting diagnoses, lost hope, and ongoing suffering reported in interviews with 20 people with persistent LBP discussing the transition from a ‘well person’ to a ‘pain afflicted’ person (Holloway et al., 2000), highlight the significant impact musculoskeletal pain can have on an individual.

People with lower socioeconomic status and education levels are particularly disadvantaged (Karran et al., 2020), with disabling LBP and early retirement due to persistent symptoms being overrepresented among these groups (Lacey et al., 2013; Shmagel et al., 2016). Experiencing LBP can also contribute to more income poverty, reinforcing a vicious cycle of poverty and social inequality (Schofield et al., 2012), that is amplified in poorer regions of the world (Buchbinder et al., 2020). Further, those living with a disability that also experience persistent LBP are more likely to report limitations and restrictions related to mobility, self-care, employment, and social participation than those without a persistent LBP problem (Australian Institute of Health and Welfare, 2020). A recent systematic review and narrative synthesis called for the need for greater recognition of the social determinants of health among LBP research (Karran et al., 2020). The authors reported on a clear link between social risk factors (including education status, lower socioeconomic status, and occupational factors) and adverse outcomes among those with persistent LBP (Karran et al., 2020), highlighting that the 'social' aspect in 'biopsychosocial' can often be overlooked.

The significant impact of LBP reflects both the high individual burden and the prevalence of the condition. The point prevalence from the Vos et al. (2015) study was 7.3% globally. In the 2017-2018 National Health Survey, 16% (about 4 million people) of Australians reported having back problems (Australian Institute of Health and Welfare, 2020). However, other data suggest that the point prevalence of LBP with any related disability (low to severe) in Australia was 25.6% (95% CI [23.6, 27.5]), the 12-month prevalence 67.6% (95% CI [65.5, 69.7]), and lifetime prevalence was 79.2% (95% CI [77.3, 81.0]), with 10.5% of Australians having experienced high-disability LBP in the previous 6-month period (Walker et al., 2004). Like the presence of persistent, disabling LBP described above, LBP prevalence estimates in Australia and other parts of the world vary depending on the definition and method used.

Low back pain is the second most common symptom that people visit their doctor for (upper respiratory/cough symptoms were the most common) (Finley et al., 2018; Hart et al., 1995). It is by far the most common painful area for which people seek care with 30% percent of visits to an Australian general practice with a special interest in musculoskeletal pain being due to LBP, more than twice as common as the next body area, the shoulder (Masters & Lind, 2010). Additionally, 44.6% of 37,465 adults referred to specialist pain management services in Australia reported the main site was their back, with the next most common being the arm/shoulder at 10.9% (Tardif et al., 2018). Amongst musculoskeletal conditions, it appears that nothing comes close to being as common, costly, and disabling as LBP.

2.1.2.1 The economic burden of LBP

Along with the significant individual burden of LBP, and its high prevalence, it also carries a significant economic burden, with the approximately 10-20% of people with persistent, disabling LBP accounting for most of this burden (Abenhaim & Suissa, 1987; Buchbinder & Underwood, 2012; Kent & Keating, 2005). Out of 154 health conditions studied in 2016 in the United States, back pain was the most costly - more than heart disease, diabetes, and cancer individually (Dieleman et al., 2020). In 2016 alone, over US$134 billion was spent on healthcare for spinal pain (paid for by private insurance, public insurance, and out-of-pocket payments) (Dieleman et al., 2020). This figure has increased by 6.7% annually since 1996 (Dieleman et al., 2020). In

Australia, LBP costs nearly A$1.2 billion in direct healthcare costs annually, equal to 1.8% of the total healthcare expenditure (Australian Institute of Health and Welfare, 2016) (Australian Institute of Health and Welfare, 2014, 2020). This number excludes a number of additional costs (capital expenditure, some non-admitted patient costs and public health programs, and costs incurred by the individual such as physiotherapy, chiropractic, osteopathic, massage, other care, or over the counter medications), and indirect costs (including lost productivity) (Australian Institute of Health and Welfare, 2014, 2020). In a study that did include those additional costs, the cost was reported to be A$4.8 billion in 2012 (Arthritis and Osteoporosis Victoria, 2013). The overall indirect cost of pain in Australia (of which LBP makes up a large proportion) was estimated to be A$139.3 billion in 2018 (A$12.2 billion in health system costs, A$48.3 billion in productivity loss, A$12.7 billion in other financial costs (informal care, aids, modifications, and deadweight losses), and A$66.1 billion in estimated value of lost quality of life (Deloitte, 2019). Worryingly, the total indirect cost of pain in Australia is expected to rise to A$215.6 billion by 2050 if nothing changes (Deloitte, 2019).

2.1.3 The cause of low back pain

Despite contention, and contrary to popular belief, being able to confidently attribute a specific pathoanatomical cause for LBP is rare (Maher et al., 2017), with most (commonly cited as 90%) (Koes et al., 2006) LBP being classified as non-specific. The remaining approximately 10% of people with LBP comprise of those with significant neurological deficit (commonly due to a disc herniation), and those with serious or systemic pathology (Hartvigsen et al., 2018; O'Sullivan & Lin, 2014). The prevalence of serious causes of LBP in primary care has been reported as 4% with a compression fracture, 3% with spinal stenosis, 2% with visceral disease, 0.7% with a tumour or metastasis, and 0.01% with an infection (Deyo & Weinstein, 2001). This is supported by a Dutch study of 669 people with LBP aged over 55 years, with 5% having a fracture, and 0.6% having a spinal malignancy (Enthoven et al., 2016). In contrast, an Australian study of 1,172 patients in primary care showed less than 0.7% had a fracture, with 0.2% having an inflammatory disorder and 0.1% having cauda equina syndrome (Henschke et al., 2009), however this included all ages, not just those over 55 years as was the case in the Dutch study.

Unless otherwise indicated, non-specific LBP (NSLBP) and LBP will be used interchangeably hereafter in this thesis.

2.1.4 The current understanding of low back pain

Historically, LBP was understood as a symptom secondary to presumed damaged structures or biomechanical faults (O'Sullivan et al., 2016). However, there is now overwhelming evidence that lower back symptoms (particularly once serious and specific pathology has been excluded) are a multidimensional phenomenon influenced by multiple broad biopsychosocial factors, and are not purely a measure of damage or local tissue pathology (Hartvigsen et al., 2018; O'Sullivan, 2012). A contemporary understanding of LBP in this context recognises it as a protective mechanism produced by the neuro-immune-endocrine system secondary to the perception of danger, threat, or the disruption of homeostasis in an individual (Marchand et al., 2005; Moseley & Butler, 2015; Wand et al., 2011).

It appears that a dynamic interplay between numerous interrelated factors occurs in LBP (Costa Lda et al., 2011; Geisser et al., 2004; Thomas & France, 2007). These factors include genetic/epigenetic factors (pathoanatomy, psychological, pain processing, comorbidities) (Bartley & Fillingim, 2013; Battié et al., 2007; Brinjikji et al., 2015), life-stage factors (childhood, adolescence, pregnancy, menopause, elderly) (Dunn et al., 2013), and system changes (central and peripheral nervous system, neuro-endocrine-immune, sensorimotor) (Lim et al., 2020; Morris et al., 2020; Ongaro & Kaptchuk, 2019; Wallwork et al., 2016). These contributors can be influenced positively (protective/resilience factors) or negatively (provocative/vulnerability factors) by numerous psychological (pain related cognitions, emotions and coping responses) factors (Burton et al., 1995; O'Sullivan et al., 2018; Pincus et al., 2002; Vlaeyen et al., 2016), social factors (Hestbaek et al., 2008; Hoogendoorn et al., 2000; Karran et al., 2020), physical factors (Karayannis et al., 2016; Marras et al., 1995; O'Sullivan, 2005), or lifestyle factors (Björck-van Dijken et al., 2008; Kelly et al., 2011; Shiri et al., 2009).

The amount these different factors contribute and the way they influence each other is highly variable, both between people, but also within the same person over time (O'Sullivan, 2012). This creates a dynamic and fluctuating presentation that is person-specific, at a specific point in time, in a specific context (O'Sullivan et al., 2018; Wallwork et al., 2016). Similarly, not only are contributions to LBP extensive and diverse, but how different people respond to the experience of LBP is also highly variable (Beyera et al., 2019; Ferreira et al., 2010). Together, this contemporary understanding recognises LBP as a heterogenous condition.

Among the heterogenous factors that can contribute to LBP, movement and posture are commonly believed to be important for people with LBP and clinicians that treat LBP (Darlow, Perry, Stanley, et al., 2014; Sahrmann, 2021). Low back movement and postures can be both threatening, provocative, and negative ('I have to be careful with, or avoid, dangerous activities')(Bunzli et al., 2017; Darlow et al., 2015), and therapeutic and positive ('I've got to keep moving and stay active' and 'bending your back is good for it')(Bunzli et al., 2017; Darlow, Perry, Stanley, et al., 2014; Hodges & Smeets, 2015; Nolan, O'Sullivan, et al., 2019; Osborn-Jenkins & Roberts, 2021).

Under the International Classification of Functioning, Disability and Health, movements and postures represent 'body structure and function' that can influence a person's ability to perform activities of daily living, and therefore participate in life situations (World Health Organization, 2001). Therefore, the term 'activity limitation' (which sits under the umbrella term of 'disability') will be used hereafter in this thesis when describing the impact and consequences of LBP (World Health Organization, 2001). Pain will be defined as "an unpleasant sensory and emotional experience associated with, or resembling that associated with, actual or potential tissue damage" (p1977)(Raja et al., 2020).

2.1.5 Beliefs about movement, posture, and LBP

Beliefs about LBP in people without pain at baseline are associated with the development of future disabling LBP (Alyousef et al., 2018; Picavet et al., 2002). Similarly, LBP beliefs among people with acute LBP are associated with future LBP-related activity limitation (Burton et al., 1995; Linton, 2000; Pincus et al., 2002). People with LBP that seek care generally have negative beliefs about their pain; that it is a sign of something structurally wrong with their back, or that it is injured or damaged in some way (Bunzli, Smith, Schütze, et al., 2015; Darlow et al., 2015; Setchell et al., 2017). Commonly, these originate from encounters with healthcare professionals (Setchell et al., 2017), but there is also evidence that these beliefs are present among society, including in people without pain (Caneiro et al., 2018; Darlow, 2016; Darlow, Perry, Stanley, et al., 2014).

Beliefs that are negative and potentially inaccurate (such as the need to protect perceived damaged structures) can also lead to unhelpful responses such as fear and avoidance (Caneiro et al., 2020; Vlaeyen et al., 2016). Given the associative nature of negative beliefs, it's no surprise that education (that includes addressing unhelpful beliefs) is a consistent recommendation from clinical practice guidelines for LBP

(Bernstein et al., 2017; Chalmers & Madden, 2019; Foster et al., 2018; Oliveira et al., 2018). But there are varying beliefs about movement and posture in people with LBP, and among clinicians that treat LBP.

2.1.5.1 Beliefs of a relationship between movement, posture, and LBP

Among society, there are strong beliefs that 'proper' lifting technique, 'good' posture that is not flexed or slumped, the avoidance of painful movements, keeping the back straight, having a strong core, and being careful with movements and postures are required to protect the back from damage and consequential pain and activity limitation (Caneiro et al., 2018; Darlow, Perry, Stanley, et al., 2014; O'Sullivan et al., 2013). Out of 602 responses from a national survey of the attitudes and beliefs about back pain in New Zealand, 99% thought that 'good posture' was important to protect the back (Darlow, Perry, Stanley, et al., 2014), highlighting how widespread these beliefs are.

Unsurprisingly, strong beliefs of a relationship are also present among people experiencing LBP. Controlling posture, being careful with or avoiding painful movements, strengthening and bracing core muscles, not bending or twisting, and keeping a straight back when lifting are common beliefs among people with LBP (Darlow, 2016; Darlow et al., 2015; Lin et al., 2013), both consciously and subconsciously (Caneiro et al., 2017). Additionally, the belief that being able to move more freely represents a signal of recovery (Hush et al., 2009) further highlights the strong belief of a relationship between movement, posture, and LBP among people with LBP.

Among the healthcare professionals that treat LBP, many hold strong beliefs that movement and posture are related to LBP, with some believing that 'movement dysfunction' is the cause of musculoskeletal pain and that physiotherapy practitioners are to be "recognized as movement experts functioning at the doctoral level" (p.1 (Sahrmann, 2021)). When assessing LBP, the observation of movement and posture is commonplace amongst health professionals (Macrae & Wright, 1969; Vaisy et al., 2015; van Dijk et al., 2020; van Dijk et al., 2017), and numerous movement and postural-based classification and treatment approaches exist in an effort to help improve LBP (Hodges & Smeets, 2015; Karayannis et al., 2016; Poitras et al., 2005; Sahrmann et al., 2017; van Dieën et al., 2018). Further, movement training and postural assessment and adjustment are common features among the ergonomic industry and occupational health and safety training. This is despite multiple systematic reviews identifying limited evidence that ergonomic and manual handling interventions are effective in preventing or treating LBP (Clemes et al., 2010; Haslam et al., 2007; Hogan et al., 2014; Martimo et al., 2008; Verbeek et al., 2011).

A dominant movement and postural narrative originating in the 1990s is the concept of 'spine stability'. This suggests that mechanical stability of the spine is required for the upper body to transmit forces on the lower body to perform everyday activities (Cholewicki & McGill, 1996). One mechanism believed to provide this stability was through sustained, and specific muscle contractions to stabilise the spine, provide stiffness, and prevent spinal structure microtrauma (Panjabi, 1992; Richardson et al., 1999). Sometimes known as 'the instability' hypothesis (Panjabi, 1992), this theory dominated much of the research in the 1990s and early 2000s, especially following the finding that people with a history of LBP showed delays in the contraction of deep intrinsic muscles such as the transversus abdominus and the multifidus when moving peripheral limbs (Hodges & Richardson, 1996, 1998; Lederman, 2010), although this was only on 15 people with a history of recurrent LBP and minimal or absent symptoms at the time of investigation (Hodges & Richardson, 1998). This research led to the formation and basis of stabilisation or 'core stability' exercises (Smith et al., 2014).

Stabilisation exercises quickly grew in popularity, becoming the most common form of physiotherapy treatment for back pain in the UK (Liddle et al., 2009; May & Johnson, 2008). However, this hypothesis has received criticism in more recent times due to its "simplistic approach to a condition that may involve complex biopsychosocial factors" (p.94)(Lederman, 2010) in addition to potentially distracting from dominant drivers that maintain chronicity and inadvertently re-enforcing a patient's erroneous belief that there is something seriously structurally wrong with their back (Lederman, 2010; O'Sullivan, 2012). Additionally, there is strong evidence that stabilisation exercises that target these proposed mechanisms are not more effective than other active exercises in the long term (Smith et al., 2014), or that baseline measures or changes in measures of stability relate to a good clinical outcome (Mannion et al., 2012; Mannion et al., 2010), raising questions about these proposed mechanisms in maintaining LBP. Further, strong evidence that stabilising the spine to prevent instability through surgical fusion is not more effective than non-operative care (Bernstein et al., 2017; Mannion et al., 2016) raises additional questions about the plausibility of the instability hypothesis.

Like the belief that instability causes stress and microtrauma, altered movement (where the lumbar spine moves *more readily,* sooner, or farther than adjacent joints or than what is ideal) has also been hypothesised to cause an accumulation of tissue stress and therefore LBP (Van Dillen et al., 2013). This potential explanation for repeated movements and sustained alignments during everyday activities has been reported as the kinesiopathological model (Van Dillen et al., 2013). The kinesiopathological model has led to the development of the Movement System Impairment Syndrome diagnosis and classification scheme for LBP (Sahrmann et al., 2017), further highlighting the presence of strong beliefs of a relationship between movement, posture, and low back pain.

The term 'movement' can mean different things for different people depending on the context (Nicholls et al., 2015). The current understanding of movement and posture as it relates to LBP, views it as an emergent phenomena that considers environmental, task, and contextual constraints (Guccione et al., 2018), as well as an individual's cognitions, emotions, and behavioural responses to pain (O'Sullivan et al., 2016; O'Sullivan et al., 2018). This positions movement and posture away from an exclusive emphasis on anatomical and biomechanical perspectives, to a whole-person, multidimensional, and individualised phenomena, consistent with the complex adaptive systems theory (Brown, 2009; Guccione et al., 2018).

While the belief that movement and posture is important in LBP is extremely common, it is not universal. The traditional and common societal and healthcare explanations about the causes of low back pain are dominantly structural, biomedical narratives (Bunzli, Smith, Schütze, et al., 2015; Cholewicki & McGill, 1996; Darlow et al., 2015; Panjabi, 1992; Setchell et al., 2017). These structural explanations suggest that changes in movement and posture may merely be an epiphenomenon to pain from injury or damaged structures (Hodges & Smeets, 2015; Mulholland, 2008), with patterns of painful movement believed to be indicative of specific underlying pathology (i.e., pain with flexion being due to an annular tear or prolapse of the disc and pain with extension being due to a facet joint (Speed, 2004)) rather than a contributing factor in itself.

In summary, while many people in society including patients with LBP and clinicians believe there is a strong relationship between movement, posture, and LBP, this is not universal.

2.1.6 Key points

What is known and not known about LBP?

- Low back pain is a common, costly, and disabling condition.
- In approximately 90% of people experiencing LBP, no specific structure can be reliably identified as causative, resulting in a diagnosis of non-specific LBP.
- Multiple, interacting factors across the biopsychosocial domain contribute to LBP.
- Movement and posture are common factors believed to contribute to LBP and are the frequent target of interventions aimed at improving LBP.

2.2 Literature investigating the relationship between movement, posture, and low back pain

For a belief as common as the relationship between movement, posture, and LBP, it would be expected that an abundance of scientific evidence exists supporting this view. However, there is little high-quality evidence that movements and postures cause low back pain. A series of systematic reviews in 2010 aimed at investigating a causal relationship between common movements or postures and LBP found no high-quality evidence that strongly supports a causal relationship for occupational bending, twisting, lifting, sitting, standing, walking, or awkward postures in accordance to the Bradford-Hill criteria of causality (Roffey et al., 2010a, 2010b, 2010c; Wai et al., 2010a, 2010b). Further, a systematic review of 41 systematic reviews in 2020 investigating spinal postures and physical activities identified evidence of association, but no evidence that implicates spinal postures and movements as causing LBP (Swain et al., 2020). This is in contrast to what people with LBP frequently report as triggering their LBP, with reports of heavy lifting and awkward postures common before the onset of LBP (da Silva et al., 2019; Steffens et al., 2015).

So, despite the availability of many systematic reviews, there is limited evidence linking specific movements and postures as *causative* of LBP (Swain et al., 2020). Within the systematic reviews, however, there are studies that provide useful insights into trying to understand the relationship between movement, posture, and LBP, both cross-sectionally and longitudinally.

2.2.1 Literature about the *movement* and LBP relationship

Keeping the spine moving and staying active are believed to be good for LBP (Darlow, Perry, Stanley, et al., 2014; Hodges & Smeets, 2015; Liddle et al., 2007; Nolan, O'Sullivan, et al., 2019), with guidelines for the management of LBP consistently reporting the importance of resuming normal activities and avoiding bed rest (Koes et al., 2010; Oliveira et al., 2018). However, within a New Zealand study, 94% of randomly selected participants from the electoral role believed that it was not safe to move and lift without bending the knees (to reduce lumbar flexion), and 95% believing they could injure their back if they weren't careful (Darlow, Perry, Stanley, et al., 2014), highlighting caveats to the view that movement is beneficial. Further, people with and without LBP hold implicit beliefs as to what type of movement is safest, with round back bending and lifting consistently being thought of as dangerous among general populations with and without LBP (Caneiro et al., 2018; Caneiro et al., 2017). Among 52 dancers (20 with a history of disabling LBP), however, extension was perceived as more dangerous than flexion (Hendry et al., 2019), suggesting a contextual, cultural, or environmental learning aspect to movement related beliefs.

Literature investigating the relationship between movement and LBP has examined it both at a single point in time comparing people with and without LBP (cross-sectional), and over time where changes in movement are compared to changes in pain or activity limitation (longitudinal).

2.2.1.1 Cross-sectional relationship between movement and LBP

A systematic review by Laird et al. (2014) aimed to identify studies that compared biomechanical aspects of lumbo-pelvic movement in people with and without LBP and summarise whether there were any consistent differences between groups. The review identified 43 suitable studies and found that, compared to people without LBP, on average, people with LBP display reduced lumbar ROM (summarised from 19 studies), slower movement (summarised from 8 studies), but no difference in lumbar relative to hip contribution during forward bending (summarised from 4 studies) (Laird et al., 2014). While it would be interesting to investigate the influence of pain intensity or the degree of activity limitation on movement, high heterogeneity of the included studies precluded such analyses (Laird et al., 2014). Among the included studies in this review, there was a lack of reported assessor blinding and multiple other factors (such as not using the same assessor to measure both those with and without LBP, not using standardized movement instructions) that increase the possibility of measurement bias. Additionally, no GRADE rating of the quality of evidence and strength of recommendations was conducted, further limiting an ability to evaluate confidence in the findings (Guyatt et al., 2008). Furthermore, the inclusion criteria of studies in this review often did not specify that participants must have LBP related to the specific movement that was measured. Commonly, a variety of different movements were recorded (for example flexion, extension, lateral flexion, and rotation) for all participants. This could potentially lead to a 'washout' effect (type II error) if only some people have problems with specific movements (such as flexion), yet it is measured in all participants. This is discussed further in Section 2.2.3.

In addition to kinematics, measures of muscle activity using Electromyography (EMG) can provide further insights into movement patterns in people with LBP compared to those without. While recording, filtering, and interpreting EMG findings has been described as a notoriously ambiguous endeavour (Türker, 1993), there are some clear signals that people with LBP show different muscle activation patterns compared to those without. A systematic meta-analytic review of surface 44 EMG studies identified that measures of flexion-relaxation demonstrated a very high effect size (d = -1.71) and good accuracy at distinguishing people with LBP from those without (Geisser et al., 2005). The flexion-relaxation phenomenon refers to the period of electrical silence or relaxation of trunk muscles (most commonly the trunk extensor or paraspinal muscles) at terminal forward trunk flexion commonly observed in people without LBP (Watson, Booker, Main, et al., 1997). People with LBP, however, typically display an *absence* of muscle relaxation at terminal forward flexion of the spine in standing. While EMG technically measures electrical activity, the term 'muscle activity' will be used in this thesis when referencing EMG measures.

There have been several ratios developed to standardise measures of flexion-relaxation, with the most common being comparison of the mean muscle activity during the dynamic forward flexion phase to the mean activity during static full flexion, with a smaller ratio denoting less relaxation (or more activity and, therefore, potentially more guarding). It should be noted however that several factors influence this ratio, such as the speed of forward flexion (den Otter et al., 2004), the range of forward flexion (as a certain ROM is required to allow the passive structures to take the weight of the upper body and therefore allow relaxation of the paraspinal muscles)

(Hashemirad et al., 2009), the level of pain or activity limitation (Alschuler et al., 2009), as well as psychological factors such as fear (Alschuler et al., 2009; Geisser et al., 2004). Nevertheless, the flexion-relaxation ratio has been shown to accurately distinguish 76% of those with LBP in a 2005 systematic review, highlighting its potential as a useful biomarker of LBP (Geisser et al., 2005).

A more recent study by Laird et al. (2019) of 266 people (140 with LBP, 126 without LBP) support the above findings, with reduced ROM, slower movement, and greater lumbar extensor activity during forward bending being more prevalent in the LBP group compared to the no-LBP group. Additionally, latent class analysis of the 140 people with LBP revealed distinct subgroups with an unequal distribution of people with and without LBP (Laird et al., 2019). Progressively slower movement and less ROM were seen as the subgroups had higher percentages of people with LBP (Laird et al., 2018). In the subgroup with the highest percentage of LBP membership, described as the 'guarded' subgroup (n = 19 people, 100% with LBP), direction-specific pain and activity limitation was greatest compared to the other groups (Laird et al., 2018). This suggests that high pain and activity limitation levels may influence movement to a greater extent than lower pain or activity limitation. Similar findings of slower, less, and altered movement in 17 males in their twenties with LBP were found by Tsang et al. (2017). In addition to slower movement, Bourigua et al. (2014) showed that 28 women and 21 men with LBP also exhibit 'freezing like' behaviours when asked to move fast (Bourigua et al., 2014). Together, these findings suggest the presence of a more protective pattern of standing forward bending in people with LBP.

In regards to the important functional task of lifting, two recent systematic reviews compared the kinematics and muscle activity of people with and without LBP (Nolan, O'Sullivan, et al., 2019; Saraceni et al., 2020). When measuring intra-lumbar angle, no differences were observed in a meta-analysis conducted by Saraceni et al. (2020), however, when measuring lumbar flexion using the less precise thoraco-pelvic angle, people with LBP kept their back 6.0° (95% CI [-11.2°, -0.9°], P = 0.02) straighter during lifting. Despite the low overall quality of the studies according to GRADE assessment, these findings suggest that people with LBP appear to follow common advice to 'keep the back straight' more so than people that don't have LBP (Saraceni et al., 2020). This was supported by the Nolan et al. (2019) review that showed people with more severe LBP lift with less spinal ROM and greater muscle activity than those without LBP. In that review, kinematic and EMG differences were more marked in the studies where participants had higher levels of pain (numerical rating scale (NRS) of pain greater than 4.7 out of 10) (Nolan, O'Sullivan, et al., 2019). While studies that did not report activity limitation or pain levels, or reported low pain intensity levels, generally showed no differences (Nolan, O'Sullivan, et al., 2019), further suggesting a link with higher pain and more changes to movement. Furthermore, people with LBP lifted more slowly, used their legs more than their back (especially when initiating the lift), and jerked less (Nolan, O'Sullivan, et al., 2019).

No GRADE assessment of overall quality was performed in the Nolan et al. (2019) systematic review. Further, several studies demonstrated multiple instances where they failed critical quality appraisal checklist items based on the independent assessments of two authors, increasing their risk of bias (Nolan, O'Sullivan, et al., 2019). When comparing sit-to-stand movements, a systematic review including eight cross-sectional studies of overall low-quality according to GRADE assessment also found that those with LBP take longer to complete the task, move their spine less, and move with reduced velocity and acceleration of the trunk (Sedrez et al., 2019).

While this thesis focuses on volitional spinal movements and the parameters related to this deliberate, dynamic spinal movement, several other parameters related to movement have also shown differences in people with and without LBP. Examples include greater movement variability and reduced proprioception (Laird et al., 2014), altered activation of trunk muscles associated with movements of the limb (Hodges & Richardson, 1998, 1999), changes in cross-sectional area of trunk muscles (Fortin & Macedo, 2013; Parkkola et al., 1993), reduced trunk muscle thickness change during contraction (such as the abdominal drawing in manoeuvre) (Critchley & Coutts, 2002; Wallwork et al., 2009), reduced trunk muscle strength and endurance (Holmström et al., 1992; Jorgensen & Nicolaisen, 1987), more co-contraction of trunk muscles and greater posterior pelvic title at the catch, greater hip extension at the finish during rowing (Nugent et al., 2021), greater trunk muscle activity and a stiffer lumbo-pelvic region during gait (Ghamkhar & Kahlaee, 2015; Koch & Hänsel, 2018), and differences in other movement parameters. While these factors may play a role in LBP, they were not investigated in detail to narrow the focus of this thesis and increase generalisability to the common movements and postures reported as problematic by people with LBP (Mitchell et al., 2010).

In summary, notwithstanding a lack of high-quality studies, systematic reviews identify that when comparing the movement of people with and without LBP, those with LBP generally display a more *protective* pattern of movement. This protective pattern is characterised by less ROM, slower movement, and increased lower back muscle activity or trunk muscle co-contraction. There is some indication that worse pain or activity limitation are associated with greater differences between people with and without LBP. Therefore, there is a possible dose-response link between pain or activity limitation intensity and the degree of protective movement. Studies also frequently did not specify whether participants had pain or activity limitation related to the movement that was being analysed. Given the heterogeneity of LBP (Maher et al., 2017), this lack of individualisation could lead to a washout of any potential differences (Dankaerts & O'Sullivan, 2011). Characteristic of cross-sectional studies, it is not possible to identify whether these differences exist prior to LBP onset, or because of LBP, nor what happens to one factor as the other changes over time.

2.2.1.2 Longitudinal relationship between movement and LBP

Capturing measures of movement over multiple timepoints, with concomitant measures of pain or activity limitation, allows a deeper understanding into whether these factors are associated or not. For example, while people with LBP may show reduced spinal ROM compared to those without, if spinal ROM doesn't increase as LBP improves, spinal ROM is less likely to be considered an important part of that LBP improvement (Mansell et al., 2013). Movement is also a common treatment target of people with LBP in the belief that a change in the targeted movement is related to an improvement in pain or activity limitation (Laird et al., 2012), however, the existing literature questions this belief.

Two systematic reviews in 2012 both showed infrequent relationships between changes in movement and changes in pain or activity limitation. Laird et al. (2012) reviewed the RCT and clinical controlled trial literature that included studies where the intervention explicitly aimed to change muscle activity patterns, lumbo-pelvic kinematic patterns, or postural patterns, and measured these before and after treatment (Laird et al., 2012). Their aim was to identify relationships between changes in movement patterns and subsequent changes in pain or activity limitation. The systematic review identified 12 suitable trials with varying designs, interventions (commonly homogenous, one-size-fits-all approaches), and outcome measures (Laird et al., 2012). The findings showed that changes in movement patterns (measured by group-level means) *infrequently* co-occurred with changes in pain or activity limitation (also measured by group-level means). Only one of six studies investigating muscle activation patterns demonstrated a change relationship, one in four studies on the flexion-relaxation phenomenon, and two of three studies investigating lumbo-pelvic kinematics or postural characteristics (Laird et al., 2012).

They concluded that movement-based interventions were infrequently successful at changing the targeted movement at a group-level, and that changes in movement at a group-level infrequently related to changes in pain or activity limitation at a group-level (Laird et al., 2012).

A similar systematic review by Steiger et al. (2012) also found little evidence supporting a relationship between changes in movement ROM and changes in pain or activity limitation. That systematic review similarly searched for randomised or non-randomised controlled trials for persistent LBP, published in English or German, using physical activity interventions (Steiger et al., 2012). Instead of comparing group-level means of movement and pain or activity limitation in the intervention group to identify whether the two changed together and were therefore related (as was the case in the Laird et al. (2012) review), they attempted to identify if there was a correlation between an individual's change in movement, and that persons change in pain or activity limitation. This method is more precise at accommodating the within-person change relationship by use of individual-level data, rather than just comparing group means for movement and pain or activity limitation. The review identified 15 studies that measured a correlation between change in movement ROM and change in pain or activity limitation, with only one out of nine studies identifying a weak correlation between movement ROM and pain, and only two out of five identifying a weak correlation between movement ROM and activity limitation (all other studies showed no correlation). The findings of that review support the Laird et al. (2012) review and further question the notion that improvements in pain or activity limitation are attributable to changes in the targeted movement parameters.

Despite the systematic review findings, improvements in finger-tip-floor distance (a surrogate measure for spinal ROM) did uniquely contribute to explaining the variance in activity limitation reduction in multiple regression in a prospective cohort study by Mannion et al. (2012) (Mannion et al., 2012). Further, changes in spinal ROM and flexion-relaxation were associated with changes in pain and activity limitation following rehabilitation of 104 people with persistent, disabling LBP, with a dose-response relationship observed (greater improvements in pain and activity limitation observed in those returning to more 'normal' ROM and flexion-relaxation measures) (Mayer et al., 2009). A return to a ROM and flexion-relaxation that resembled a pain-free group was also observed in a three-arm controlled study of a functional restoration program with surface EMG assisted stretching biofeedback protocol (Neblett et al., 2010). Further, a 2019 study by Nordstoga et al. (2019) measured flexion ROM and velocity, as well as pain, activity limitation, and fear-avoidance beliefs in 44 people with LBP at three timepoints and investigated longitudinal associations between them following physiotherapy treatment. They found that ROM was weakly associated to activity limitation (but not pain) over time (Nordstoga et al., 2019).

So, while changes in group-level movement parameters such as ROM and flexion-relaxation appear to be related in some studies, this finding is not consistent, with both systematic reviews finding that changes in movement *infrequently* relate to changes in pain or activity limitation. Both systematic reviews commented on the high heterogeneity among the included studies (Laird et al., 2012; Steiger et al., 2012). Variable study designs, intervention types, and outcome measures highlight some of the challenges when investigating this question at a systematic review level and may contribute to the overall infrequent relationship identified when trying to do this. Given the heterogeneity of LBP (Maher et al., 2017), and the multiple, interacting mechanisms that can contribute to LBP (as discussed in Section 2.1.4), generic, one-size-fits-all treatment approaches (like the ones in the included studies of the aforementioned systematic reviews) may not adequately target the mechanisms driving LBP. This may, in part, explain the overall modest effect of movement-based interventions (Hodges & Smeets, 2015). Further, if movement-based interventions target the same movement for everyone as was common in the studies in the systematic reviews, there may be a washout effect as it's unlikely that all participants had a problem with the same movement (Dankaerts & O'Sullivan, 2011).

A combination of the modest efficacy of current interventions, a lack of targeted intervention (both from the perspective of movement and broader biopsychosocial factors), and movement measurement that is not individualised can potentially preclude the ability to accurately investigate the relationship between changes in movement and changes in pain or activity limitation.

2.2.1.2.1 The relationship between movement and people that develop LBP

In addition to limited evidence supporting a relationship between changes in movement and changes in pain or activity limitation, there is limited evidence that certain movement patterns predict future LBP. In a prospective study investigating the factors that predicted new onset LBP in 117 female nursing students, Mitchell et al. (2010) measured more than 20 kinematic parameters during functional tasks such as bending and lifting (which were the most common aggravating factors in the sample who developed new onset LBP). They found that none of the kinematic factors measured at baseline predicted new onset LBP (Mitchell et al., 2010). When investigating muscle activity, a more ‘top down’ pattern (electrical activity of back extensor muscles before the gluteal muscles as opposed to the reported normal ‘gluteal before back muscle’ electrical pattern) of re-extension from standing flexion predicted those who develop LBP during a 2-hour standing task (Nelson-Wong et al., 2012). This suggests that when returning from bending (re-extension), people that develop LBP during a 2-hour standing task use a more back dominant EMG pattern. While studies examining kinematic and EMG factors that are associated with the development of transient LBP in otherwise healthy people provide some insights into the aetiology of LBP, generalisability and relevance to clinical LBP that may be persistent and disabling remains unclear.

2.2.2 Literature about the *posture* and LBP relationship

Static postures such as sitting and standing are commonly provocative for people with LBP (Mitchell et al., 2010). The belief that ‘good posture is important to protect the back’ is common in society (Darlow, Perry, Stanley, et al., 2014). The dominant belief of ‘good’ or ‘optimal’ sitting and standing posture appears to be one that is upright, lordotic, without forward head posture or rounded shoulders, and maintaining neutral/natural spinal curves (i.e. not slouching) (Korakakis et al., 2019; O’Sullivan et al., 2013; O’Sullivan et al., 2012; Slater et al., 2019). Therefore, one may reasonably assume that people that posture themselves in this way have less pain and activity limitation, are less likely to develop pain or activity limitation, and their pain or activity limitation improves in relation to them adopting this perceived ‘good posture’. Again, however, there is limited literature supporting this.

2.2.2.1 Cross-sectional relationship between posture and LBP

When comparing the kinematic and muscle activity differences in people with and without LBP using skin surface measurement techniques during static postures, such as sitting and standing, no differences in lordosis angle or standing pelvic tilt angle were found in the Laird et al. (2014) systematic review. Similarly, the Laird et al. (2019) study comparing kinematics in 140 people with LBP to 126 people without LBP found no differences in sitting position or pelvic tilt range using surface-based sensors. In contrast, a systematic review of 795 people with LBP from 13 studies in 2017 found that those with LBP demonstrate significantly less lordosis compared to

927 age-matched healthy controls using radiographic measures of upright standing lordosis (one study measured lordosis in supine) (Chun et al., 2017). This suggests that more precise measures of lumbar spine angles may reveal differences in static posture in people with and without LBP. No analysis investigating whether people with higher pain or activity limitation demonstrate greater changes in posture occurred in either systematic review.

Given the heterogeneity of LBP (Maher et al., 2017), differences may only be apparent following clinical subgrouping. For example, no differences were found in kinematics (sacral tilt, lower lumbar, and upper lumbar angle) or trunk muscle activity during usual and slumped sitting between people with and without LBP (Dankaerts et al., 2006a, 2006b). But when sub-classifying those with LBP into flexion and extension patterns of pain provocation, significant differences were found (Dankaerts et al., 2006a, 2006b). The flexion pattern participants displayed greater lumbar flexion and a trend towards less muscle activity, while the active extension pattern participants displayed greater lumbar extension (lordosis) and increased muscle activity compared to those without LBP (Dankaerts et al., 2006a, 2006b). These findings were supported in a similar study on adolescents, with differences in spinal posture only identified following subgrouping (Astfalck et al., 2010). This highlights that important postural parameters may differ between people with LBP based on their clinical presentation.

Interestingly, like the flexion-relaxation phenomenon during bending, Dankaerts et al. (2006) also found that people with LBP displayed an absence of lumbar muscle relaxation during slumped sitting compared to usual sitting, regardless of whether sub-classification was applied. This suggests that people with LBP have difficulty relaxing their back during slumping (Dankaerts et al., 2006a). In support of this, greater muscle activity during sitting and standing has also been observed in several other cross-sectional studies comparing people with and without LBP (Claus et al., 2018; Geisser et al., 2005; Mak et al., 2010; Sheeran et al., 2012).

The factors that influence posture also appear to be diverse. A large study by O'Sullivan et al. in (2011), identified that only 60% of sitting postural variation was explained by several, multifactorial variables in 1596 adolescents (O'Sullivan et al., 2011). Gender and other biopsychosocial factors such as self-efficacy, BMI, and television use appeared to strongly influence posture, while the degree of slumping was only weakly associated with pain (O'Sullivan et al., 2011). This highlights the heterogenous, complex, and biopsychosocial nature of the relationship between posture and LBP.

While this thesis is focused on the kinematic and EMG parameters related to movement and posture, other variables such as time spent in certain postures (both lordotic and flexed) have shown to be related to low back pain (Adams et al., 2006; Womersley & May, 2006). This highlights that *time* in a position may be an important consideration in addition to the kinematics and EMG parameters of the position itself.

Changes in joint reposition sense or error (Laird et al., 2014; Sheeran et al., 2012), antero-posterior sway and measures of centre of pressure (Berenshteyn et al., 2019; Ruhe et al., 2011), middle and upper spinal posture (Mahmoud et al., 2019; Richards et al., 2016; Richards et al., 2021), and postural adjustments/fidgets (Dunk & Callaghan, 2010) have also shown differences in people with pain compared to those without, but are beyond the scope of this thesis.

2.2.2.2 Longitudinal relationship between posture and LBP

While there is an indication that people with LBP may posture themselves differently to those without LBP (particularly when those with LBP are subclassified), the evidence is scarce when investigating whether *changes* in posture are related to *changes* in pain or activity limitation. There was only one study from the Laird et al. (2012) systematic review that examined changes in posture related to changes in pain or activity limitation. This study was a RCT investigating Mensendieck somatocognitive therapy (an intervention that changes posture, movement, and respiration patterns combined with standard gynaecological treatment) to standard gynaecological treatment alone in 40 women with persistent non-specific pelvic pain (Haugstad et al., 2006). It found that at a group level, changes in sitting but not standing posture co-occurred with changes in pain and activity limitation, with postures reportedly becoming more relaxed (Haugstad et al., 2006). However, in this study, posture was not assessed by an objective instrument, rather it was subjectively assessed by a single, blinded therapist scoring postural performance on a zero to seven scale (with seven representing ‘optimal’ posture and zero representing gravest deviation from this optimum) (Haugstad et al., 2006). Further, this RCT scored six out of 11 on the PEDro criteria, and did not present a flow diagram of participants through the study (therefore attrition rates are unknown) (Haugstad et al., 2006). Unknown attrition rates in addition to the subjective observations of posture question the validity of the results and highlight a distinct lack of high-quality longitudinal investigations of objectively measured postural kinematics and how they relate to changes in pain or activity limitation in people with non-specific LBP.

When it comes to EMG measures, a multiple comparative study of 25 people undergoing rehabilitation for persistent LBP identified that mean sitting flexion-relaxation ratio increased (i.e., the LBP group demonstrated a reduction in muscle activity in slumped sitting) compared to 20 people without LBP following a 12-week intensive (5 days per week) in-patient rehabilitation program (Mak et al., 2010). This increase in sitting flexion-relaxation co-occurred with an increase in subjective sitting and standing tolerance in the LBP group, but no changes in pain or activity limitation were observed at a group-level (Mak et al., 2010). A lack of change in pain or activity limitation is surprising given the intensive nature of that intervention, and the common pattern of LBP improvement following a wide range of primary care treatments (Artus et al., 2010). No other studies investigating longitudinal relationships between changes in posture and changes in pain or activity limitation among individuals with LBP were identified.

So, while improving posture is believed to be important among society and changing posture is a frequent target of clinicians, there is a stark lack of evidence supporting a relationship between changes in posture and changes in LBP.

2.2.2.2.1 The relationship between posture and people that develop LBP

A systematic review of prospective cohort studies of people free of pain at baseline identified strong evidence that the activities of sitting or sustained standing were *not* associated with LBP developing, however sitting and standing were self-report and not objectively measured (Bakker et al., 2009). Two other previous systematic reviews also found no evidence that prolonged self-report sitting was a risk for LBP (Hartvigsen et al., 2000; Hoogendoorn et al., 1999). In a study that did objectively measure sitting posture at baseline in a cohort of 117 nursing students without LBP, greater posterior pelvic tilt during slumped sitting had a weak association with new onset LBP in both univariate and multivariate analysis. For example, the univariate odds ratio between greater posterior pelvic tilt at baseline and the development of significant LBP was only 1.08 (95% CI [1.00, 1.15]). Further, this was the only postural variable out of 12 possible postural variables that showed significance in univariate analysis, and it contributed to R^2 0.111 to the overall R^2 of 0.448 of the predictive model (Mitchell et al., 2010).

Greene et al. (2019) reported no kinematic or EMG differences during one hour of sustained sitting in 90 people (61 with no history of LBP, 29 with a history of LBP) between those that developed pain during that period of sitting compared to those that didn't (Greene et al., 2019). However, Schinkel-Ivy et al. (2013) reported that the people that developed pain (four out of 10 healthy males) exhibited higher levels of trunk muscle co-contraction during a 2-hour unsupported sitting task (Schinkel-Ivy et al., 2013). Further, among those that developed pain, trunk muscle co-contraction increased over-time and was significantly correlated with pain development (Schinkel-Ivy et al., 2013).

For standing posture, a systematic review of 26 laboratory studies with 591 participants identified consistent evidence that postures such as increased spinal flexion, axial rotation, and lumbar curvature (lordosis) related to the development of standing-related low back symptoms (Coenen et al., 2017). In contrast to the findings identified during sitting, that review did not find consistent evidence that muscle co-contraction or stiffness were mechanisms in developing standing-related symptoms (Coenen et al., 2017). No GRADE or other assessment of overall quality were performed, but the majority (16 of 26 studies) were not considered to have a high risk of bias (Coenen et al., 2017).

In contrast, hip (bilateral gluteus medius) and trunk (flexor-extensor group) muscle co-contraction were predisposing factors in the development of LBP during a two-hour standing task in 43 young and healthy adults (22 males, 21 females) (Nelson-Wong & Callaghan, 2010). Not moving, that is not fidgeting and assuming static standing within 15 minutes during a 2-hour prolonged standing task, in 32 healthy, young adults was associated with prolonged standing induced LBP (Gallagher & Callaghan, 2015). Additionally, increased lumbar lordosis (mean difference 4.4° (95% CI [0.9°, 7.8°]) was found to differentiate those that developed LBP from those that did not over a 2-hour standing task in 57 people without LBP (Sorensen et al., 2015). The findings of increased lordosis being associated to the development of transient standing-related LBP from this study and the previous systematic review (Coenen et al., 2017) contrast with the finding of *less* lordosis in a systematic review of people with clinical LBP in Section 2.2.2.1 (Chun et al., 2017). Again, the relevance of transient postural pain to persistent, disabling, clinical LBP is unclear.

2.2.3 Movement and postural heterogeneity

Based on the existing literature, it is apparent that people with LBP move and posture themselves differently (seemingly more protective, guarded, and cautious) than those without LBP. However, as people with LBP improve (their pain or activity limitation changes), their movement or posture only infrequently changes in relation to this improvement. Although restricted by limited high-quality studies, this has been demonstrated when investigating the co-occurrence of mean movement, postural, pain, or activity limitation in group-level analysis (Laird et al., 2012), and using within-person correlations (Steiger et al., 2012). However, the finding that cross-sectional differences in movement or postures between people with and without LBP only become apparent when participants with LBP are subclassified based on their clinical presentation (Astfalck et al., 2010; Dankaerts et al., 2006a, 2006b; Dankaerts et al., 2009) suggests that; a) different movement and postural parameters may be important for different people with LBP, b) the movements and postures that are pain provoking are different for different people, or c) a combination of both. That is, the distinguishing kinematic and EMG parameters between those with and without LBP might be individualised, and the movement and postural tasks that people report as problematic may also be individualised, reflecting heterogeneity. In the context of cross-sectional movement or postural heterogeneity, it could be hypothesized that the longitudinal change relationship could also be heterogenous and require individualisation.

Mitchell et al. (2010) identified that of the factors that aggravated participants' pain, bending and lifting were the most common, occurring in 49% of participants (Mitchell et al., 2010). Sitting or driving were the next most common aggravating factors occurring in 30% of participants, while standing or walking aggravated 25% of participants (Mitchell et al., 2010), findings similar to Pengel et al. (2004) (Pengel et al., 2004). This implies that for 51% of the participants in the Mitchel et al. (2010) study, their pain was, presumably, not (or less) aggravated by bending or lifting. If bending ROM was measured in these 51% of people that did not have a significant problem bending, it may be reasonable to expect that there wouldn't be much limitation into bending ROM and therefore a within-person change relationship would be less likely. Similarly, if measuring the same kinematic and EMG parameters across a large group of people with LBP and intervening with the same intervention (that may or may not involve modification of movement or posture), there may be a risk of a type II error (for example a 'washout effect' may be a present (Dankaerts & O'Sullivan, 2011)).

Adding to the movement heterogeneity story, the latent class analysis of forward bending in standing in 266 people (approximately half with persistent LBP) by Laird et al. (2018) clearly identified four distinct subgroups with high classification probabilities of membership (Laird et al., 2018). These were; a) a 'standard' group (n = 133, 26% LBP) with the greatest trunk ROM, fastest movement, full flexion-relaxation, and synchronous trunk and pelvic movement, b) a 'lumbar dominant' group (n = 73, 71% LBP) with the greatest lumbar ROM, less flexion relaxation, and a lag of pelvic movement, c) a 'pelvic dominant' group (n = 41, 83% LBP) with the smallest lumbar ROM, delayed lumbar movement, and less flexion relaxation than the lumbar dominant group, and a c) 'guarded' group (n = 19, 100% LBP) with the least flexion relaxation, slowest movement, smallest pelvic ROM, and greatest delay of pelvic movement (Laird et al., 2018). So, three out of four of these kinematic and EMG derived subgroups included people with and without LBP, exemplifying the complexity present when trying to understand 'abnormal' movement in people with LBP. While this study reported different subgroups of bending kinematics and EMG, other studies have reported different pain responses to the same repeated movements, as discussed below.

A large cross-sectional study of 294 people with persistent LBP measured pain responses to 20 repeated forward and backward bends, reporting three distinct subgroups (Rabey et al., 2017). They derived a group where no clinically important increase in pain in either direction was observed (n = 144, 49%), a group with increased pain in one direction (n = 112, 38.1%), and a group with increased pain in both directions (n = 38, 12.9%) (Rabey et al., 2017). Further, these different groups showed weak associations between pain sensitivity and psychological profiles (Rabey et al., 2017), which in addition to the heterogenous pain responses following repeated movements, suggests other, potentially interacting, factors may be relevant. Other factors may include psychological factors such as fear of movement, with different people avoiding different activities for fear of damage. For example, six participants with persistent LBP in a multiple baseline single-case experimental design (SCED) study reported varied avoided activities (including running, squatting, heavy lifting, twisting) (Boersma et al., 2004).

Together, these findings suggest that when investigating the relationship between movement, posture, and LBP, assessing individually relevant movements and postures may be relevant.

2.2.4 Limitations of existing quantitative research

The approach of most studies discussed in this literature review, and the dominant lens that movement and posture is observed through, is one of group averages and treatment efficacy (as opposed to understanding relationships between changes in movement and posture, and changes in pain or activity limitation). Whilst movement and posture are a key focus in LBP research, a sizable proportion of studies needed to be excluded from the Laird et al. (2012) systematic review because they only measured movement and posture at baseline and did not perform (or report) a follow-up measure to observe whether this had changed. So, while *pain or activity limitation change* was commonly measured before and after treatment (to estimate treatment efficacy), rarely did studies measure whether the target of their treatment (the movement or posture) actually changed or not (Laird et al., 2012). This limits the ability to understand whether changes in movement or posture an important part of changes in pain or activity limitation.

While LBP is now widely understood as a complex biopsychosocial condition (Hartvigsen et al., 2018; Maher et al., 2017; O'Sullivan et al., 2016) and there have been several calls from multiple high-quality clinical practice guidelines developers to embrace this complexity and focus on patient-centred, individualised care (Hush, 2020; Lin et al., 2020), the historic focus on group-level assessment and generic treatment limits the ability to accommodate this heterogeneity. Additionally, individual spinal curvature affects preferred lifting styles (Pavlova et al., 2018) and individual structural changes (such as degeneration or protrusion) influence spinal movement parameters such as ROM (Gu et al., 2020; McGregor et al., 1997). Thus, in addition to the factors described above, the static and unique morphology of an individual's spine also appears to influence movement, further supporting the potential importance of individualising movement assessment.

In the studies summarised in the literature review thus far, there was an inability to accommodate movement, postural, and participant heterogeneity. Additionally, infrequent assessor blinding, infrequent measurement of movement and posture (typically only pre- and post, and not utilising several repeated measures), and the infrequent use of tools to accurately measure movement and posture present further limitations. Together, these may limit the ability to yield important insights into the relationship between movement, posture, and LBP.

Central to the research questions in this thesis, the current literature suggests that changes to these movement and postural parameters appear largely unrelated to concomitant changes in low back pain or activity limitation. However, this finding may be clouded by several factors, namely an inability to accommodate heterogeneity. In the context of movement and postural heterogeneity, the individualised assessment and treatment of movement or posture may reveal important insights.

2.2.5 Key points

What is known and not known about movement and posture as it relates to LBP?

- The belief that movement and posture are important for LBP is very common among society, including among people with LBP and clinicians that treat LBP.
- People with LBP typically move with less spinal range, slower, and with increased trunk muscle activity at the end range of forward bending (or an absence of flexion-relaxation) than those without LBP. They appear to follow traditional movement, lifting, and postural advice *more* than those without LBP (although this may be a response to pain rather than a behaviour that pre-dated pain).
- Changes in movement appear largely unrelated to concurrent changes in pain or activity limitation over time.
- With regards to spine posture, aside from an overall increase in muscle activity during sitting and standing, differences in posture are commonly not seen between people with and without LBP, unless those with LBP are sub-classified based on individual patterns of pain provocation. There is limited literature investigating how changes in posture relate to changes in pain or activity limitation over time. The literature that does exist suggests changes are not related.

2.3 Other factors that influence movement and posture

While some movements and postures appear to be influenced by the presence or absence of LBP and by individual variations in body morphology, psychological factors (pain related cognitions and emotions) can also influence movement, posture, and LBP. While termed psychological factors, these pain-related cognitions and emotions are influenced by societal factors and surrounding healthcare environments, as is discussed in this section. Therefore, perhaps the term psycho-*social* factors is more representative. However, as this chapter is referring to individual person factors rather than broader societal factors, the term psychological will be used. This is consistent with the terminology used in the literature, in particular when discussing the biopsychosocial model (Engel, 1978; Turk et al., 2011).

2.3.1 Psychological factors influence movement

A 2021 systematic review and meta-analysis by Christe et al. (2021) summarised 52 studies involving 3,949 people with LBP. This meta-analysis investigated whether psychological factors (pain-related fear, pain catastrophising, depression, anxiety, pain self-efficacy) were related to spinal movement amplitude and trunk muscle activity. They also investigated whether pain intensity was a confounding factor in this relationship. The findings of these cross-sectional studies indicated that greater levels of pain-related fear, pain catastrophising, and depression all significantly correlated with less spinal movement amplitude and more trunk muscle activity, irrespective of pain intensity (Christe, Crombez, et al., 2021). However, the correlation coefficients were small (ranging from r = -0.06 to = -0.16), and variable. For example, the pooled correlation coefficient (95% CI) for pain-related fear was r = -0.13 (-0.18, -0.09) and ranged from r = -0.52 (-0.66, -0.35) to r = 0.06 (-0.22, 0.33), while for pain-catastrophising the pooled correlation coefficient (95% CI) was -0.16 (-0.23, -0.09) ranging from r = -0.44 (-0.81, 0.18) to r = 0.46 (0.05, 0.74). The significant range between the most negative and most positive correlation coefficients highlights how variable the strength of the relationship between psychological factors and movement is within the literature. The small correlation coefficients lead to the authors questioning the role of psychological factors as major contributors to altered spinal movement. They acknowledged that the lack of strong associations observed may be due to the use of generalised measures of psychological factors and spinal movement that couldn't accommodate avoidance or fear that is context dependent and variable across individuals (Christe, Crombez, et al., 2021). The authors also recommended further experimental studies with person-specific and individualised measures of psychological factors, pain, and spinal movement to account for this patient heterogeneity (Christe, Crombez, et al., 2021).

While generalised measures of psychological factors appear to be weakly associated with spinal movement, there is an indication that individualised, or task-specific measures show stronger associations. For example, a study by Matheve et al. (2019) identified that lumbar ROM during a lifting task was predicted by task-specific, but not general, measures of pain-related fear in 55 people with persistent LBP compared to 54 people without LBP (Matheve et al., 2019). This led the authors to recommend the use of task-specific pain-related fear when measuring the relationship with movement (Matheve et al., 2019).

Several other studies of people with LBP have also identified a link between reduced movement amplitude, reduced speed, greater trunk muscle activity or task avoidance, and higher levels of pain-related fear and kinesiophobia (Geisser et al., 2004; Karayannis et al., 2013; Osumi et al., 2019; Thomas & France, 2007; Thomas et al., 2008; Vlaeyen et al., 1995; Watson, Booker, & Main, 1997). Similarly, higher pain catastrophising (Pakzad et al., 2016), poorer self-efficacy (La Touche et al., 2019; Watson, Booker, & Main, 1997), and increased stress (Glombiewski et al., 2008) have shown associations with more protective patterns. Even in people without LBP, more negative fear avoidance beliefs are associated with reduced lumbar spinal flexion during lifting (Knechtle et al., 2021). It is noteworthy that this pattern of a relationship between more negative psychological factors and more protective movement has also been observed in a systematic review assessing musculoskeletal pain in areas peripheral to the lumbar spine (for example knee pain) (De Baets et al., 2020).

While protective spinal movement behaviours appear to be associated with more negative psychological factors, LBP can also be associated with avoidance behaviours, as reported in the fear avoidance model (FAM) (Vlaeyen et al., 2016). The FAM suggests that following injury or pain, a cycle of catastrophizing and fear of movement or re-injury leads to the avoidance and hypervigilance of movement that could cause damage or re-injury, resulting in disuse, disability, and depression, further contributing to pain (Vlaeyen et al., 2016). Pain-related fear can also generalise to other contexts through associative learning processes (Meulders & Vlaeyen, 2013), with evidence identifying protective or avoidance behavioural responses driven by pain-related fear occurring simply following the *intention* to perform painful movements (Meulders & Vlaeyen, 2013). Fear of movement can also be acquired through observation or secondary to threatening verbal information (den Hollander et al., 2010; Goubert et al., 2011; Helsen et al., 2011), highlighting the multidimensional process of developing negative psychological factors which is discussed further in the next section (Section 2.3.1.1).

While avoidance may be one behavioural response to pain, the enduring persistence of valued activities has also been reported. The avoidance-endurance model of behaviour supports the established evidence behind the FAM, but also suggests the presence of two endurance-related responses related to poorer outcomes (Hasenbring & Verbunt, 2010), although there is incomplete evidence to confirm the hypothesized negative consequences of these subgroups. The first response (distress endurance response) is reportedly characterised by distress, thought suppression, anxiety, depression, and task/pain persistence behaviours, while the second (eustress endurance response) is characterised by ignoring or minimising the pain, positive mood despite the pain as well as task/pain persistence behaviours (Hasenbring & Verbunt, 2010). This model supports the presence of avoidance and persistence behaviours (that may be protective or guarded) when people with LBP are faced with painful or threatening activities, movements, and postures.

There is limited research investigating how psychological factors influence posture in people with LBP. Data from 1,596 non-care seeking adolescents highlights that lower perceived self-efficacy is associated with slumped sitting kinematics, but with minimal associations observed between posture and LBP (O'Sullivan et al., 2011). Data from that same cohort also identified that those with a more slumped neck posture were at higher odds of depression (Richards et al., 2016), highlighting that psychological factors can also be associated with spinal postures cephalad to the lumbar spine. No other studies investigating the association between psychological factors and static lumbar spinal posture were identified.

2.3.1.1 The origin of negative psychological factors

While negative psychological factors, such as unhelpful LBP beliefs, are apparent across society and this likely informs or amplifies the beliefs of people once they develop LBP (Caneiro et al., 2018; Darlow, Perry, Stanley, et al., 2014), it appears that frequently, people with LBP report they acquire these beliefs secondary to encounters with their healthcare professionals (Darlow et al., 2013; Setchell et al., 2017) or from manual-handling trainers (Nolan et al., 2021).

A 2013 systematic review highlighted that clinician LBP beliefs are strongly associated with the LBP beliefs of their patients (Darlow et al., 2012). There is also evidence that higher levels of kinesiophobia in second year physical therapy students negatively influences their 'patients' (first year physical therapy students) lifting capacity (Lakke et al., 2015), suggesting the possibility that clinician psychological factors could subconsciously influence the performance of functional tasks by their patients, but this requires further testing. Similarly, negative clinician fear avoidance beliefs are associated with more conservative management advice (such as recommending activity avoidance or bed rest) that is non-concordant with guidelines for the management of LBP (Coudeyre et al., 2006). This finding has been reproduced in Australian physiotherapists (n = 75) and exercise physiologists (n = 75), with more biomedical attitudes and beliefs being associated with more conservative advice that could reflect going against practice guidelines (Gibbs et al., 2021).

When it comes to manual handling training, in the study by Nolan et al. (2021), 151 National Health Service employees in the UK had LBP beliefs measured before and after traditional 'protect your back' manual handling training. These employees already held negative beliefs about the relationship between pain and injury and had strong negative beliefs about the vulnerability of the back before the manual handling training (Nolan et al., 2021), highlighting the strong societal influence previously mentioned. Following the training however, they had *worse* LBP-related cognitions (Nolan et al., 2021). Similarly, in a study of 129 Irish healthcare workers undergoing manual handling training, common daily activities scored on the modified Photographs of Daily Activities (mPHODA) were considered significantly more harmful following manual handling training, despite back beliefs and fear of movement improving (Horgan et al., 2020). Additionally, their results indicated differences depending on age, that may reflect socio-cultural time-periods (Horgan et al., 2020).

Together, these findings highlight the multidimensional influence that various contextual and societal factors have on the movement and postural beliefs and behaviours of people with LBP, with the psychological factors of healthcare practitioners appearing to be particularly influential.

2.3.1.2 Psychological factors also influence outcome

In addition to psychological factors influencing movement and posture, they also influence outcome. There is strong evidence that negative psychological factors negatively influence LBP and can increase the risk of pain persisting (Alhowimel et al., 2018; Burton et al., 1995; Linton, 2000; Pincus et al., 2002; Woby et al., 2008). Psychological factors also mediate treatment outcome (Lee et al., 2015; Mansell et al., 2016; Mansell, Hill, et al., 2017) and have been shown to relate more strongly to changes in LBP and activity limitation than movement or posture (Mannion et al., 2001; Mannion et al., 2010; Mitchell et al., 2010; Nordstoga et al., 2019). This has also been observed in other body areas, for example psychosocial factors showed stronger associations with shoulder pain outcomes than physical factors in a multicentre longitudinal cohort study of 1,030 people (Chester et al., 2018). Similarly, consistent associations between higher patient recovery beliefs/expectations and better outcomes from several systematic reviews across many health conditions provides further evidence of the relevance of patient psychological factors relating to clinical outcomes (Crow et al., 1999; Linde et al., 2007; Mondloch et al., 2001).

Similarly, the psychological factors of clinicians can also influence their patients' clinical outcomes. For example, clinician preference and expectation of the benefit of a treatment was significantly associated with subsequent pain and activity limitation outcomes of their patients in a RCT comparing early use of thrust manipulation versus non-thrust manipulation in 149 people with LBP (Cook et al., 2013). Another example is that clinician expectation has been shown to influence outcome even when the intervention is placebo analgesia, as reported from a renowned double-blind study of dental patients (Gracely et al., 1985).

Together, this highlights the relevance of psychological factors when considering movement, posture, and LBP outcomes. However, how psychological factors influence the longitudinal relationship between movement, posture, and LBP remains poorly understood.

2.3.2 Key points

What is known and not known about how psychological factors (pain related cognitions and emotions) influence LBP?

- Psychological factors (which are influenced by social aspects and clinician messages) influence movement and posture, as well as LBP outcomes.
- There is a consistent, significant (albeit small), and negative cross-sectional relationship between psychological factors and movement. That is, the more negative psychological factors such as pain-related fear, pain catastrophising and depression are, the more ‘protective’ spinal movement is (less ROM and increased muscle activity), irrespective of pain intensity.
- The small correlation coefficients observed for those relationships could reflect the complexities of the biopsychosocial system. Due to the heterogeneity of LBP, they could also indicate the importance of individualised and person-specific measures of psychological factors, pain, and spinal movement.
- Relevant cognitions and emotions appear to be individualised and person specific.
- Two behavioural responses, protect and avoid, are commonly observed in those with LBP, especially if more negative psychological factors are present.
- There is limited literature investigating how changes in psychological factors influence or are affected by the relationship between movement, posture, and LBP over time.

2.4 Movement and posture… common sense patient perspectives

As discussed in Section 2.1.5.1, movement and posture are common topics of consideration when discussing LBP, with most people reporting ‘correct movement and posture’ as being important to protect the back (Darlow, Perry, Stanley, et al., 2014). Interestingly, not a single person from a cohort of 100 young asymptomatic people stated that their habitual sitting was ‘optimal’, and consistently changed their posture to be more upright when asked to assume an ‘optimal’ sitting posture (Korakakis et al., 2021). This highlights how ingrained postural beliefs are amongst society, as well as the kinematic discrepancy between habitual (presumably comfortable and efficient) and perceived ‘optimal’ sitting posture. This was also true in an earlier study showing that perceived ideal posture and perceived neutral posture were both more upright than the habitual sitting posture of 17 people without pain (O'Sullivan et al., 2010). People with LBP also commonly believe that their persistent or recurrent LBP is due to poor posture (Setchell et al., 2017).

When 130 people with LBP were asked about their understanding of why their LBP was persisting or recurring, the most common reason related to a belief that their body was like a 'broken machine' secondary to poor posture or alignment issues, poor muscle or motor control, poor core strength, or poor disc health (Setchell et al., 2017). It was common for these participants to view LBP as very negative and permanent/immutable (Setchell et al., 2017). Contrary to this view, but far less common, some participants encouragingly did discuss the complexity of LBP (Setchell et al., 2017). The strong belief that LBP is very negative is supported by other qualitative studies in people with LBP. Examples include the belief that the spine is 'easy to harm and hard to heal' (Darlow et al., 2015), or that it is vulnerable to injury and has a poor prognosis (Darlow et al., 2015; Nolan et al., 2021). These strong biomedical/pathoanatomical beliefs, that can lead to the protection of spinal structures from perceived damage, (re)injury, and further pain (Caneiro et al., 2020), have been well documented in multiple qualitative studies of people with LBP (Bunzli, Smith, et al., 2016; Bunzli, Smith, Schütze, et al., 2015; Bunzli, Smith, Watkins, et al., 2015; Darlow et al., 2015; Lauridsen et al., 2020; Setchell et al., 2017; Singh et al., 2018; Stenberg et al., 2014). If the belief that pain experienced with movement is a direct reflection of tissue damage, then reducing painful movement, avoiding movement, or being protective, slow, and guarded with one's movement when avoidance is not possible, could be considered a common sense response to try and decrease pain (and therefore perceived damage) (Bunzli et al., 2017; Caneiro et al., 2020). Similarly, with the belief that 'round back lifting is dangerous' being common among people with and without LBP (Caneiro et al., 2018; Caneiro et al., 2017), avoidance of this type of lifting could be viewed as a common sense response. The specific threatening movement to avoid or protect against appears to be specific to the valued activities that are important in certain contexts. For example, while rounding the back (spinal flexion) is commonly feared in the general population (Caneiro et al., 2018; Caneiro et al., 2017), the 52 pre-professional ballet dancers reported in Section 2.2.1 above instead held negative beliefs towards *extension* (extension being an important task in ballet) (Hendry et al., 2019). The underlying belief behind the fear (that pain necessitated protection of the spine to reduce the risk of damage) however, was similar to that reported previously (Hendry et al., 2019).

2.4.1 A phobic response, or a common-sense response?

The FAM (that outlines the circular process of pain, pain-related fear, avoidance, disuse/disability/depression feeding back to increased pain) has received a lot of attention as a model to understand the behavioural response of avoidance and consequential pain chronicity and activity limitation in LBP (Vlaeyen et al., 2016). However, with evidence suggesting protective and avoidance responses to pain may also be a 'common sense' response rather than purely a fear-based 'phobic' response (Bunzli et al., 2017; Bunzli, Smith, Schütze, et al., 2015; Caneiro et al., 2017), other models have been proposed. The Common Sense Model (CSM) of illness perceptions provides a broad model to understand how people with LBP conceptualise and represent their condition (see Figure 2-1) (Bunzli et al., 2017; Bunzli, Smith, Schütze, et al., 2015; Leventhal et al., 1980; Leventhal et al., 2016). In addition to accounting for a wider sense-making process, the CSM also includes the key constructs understood to influence behaviour in musculoskeletal conditions (Bunzli et al., 2017). These key constructs include outcome expectancies, self-efficacy, goals, sociostructural factors, emotional or stress constructs, and symptom-related control (Knittle et al., 2012). Further, there is unclear empirical support for the cyclical relationships that have endured in the FAM (Wideman et al., 2013), something that the CSM circumvents using bidirectional arrows.

Figure 2-1 The Common Sense Model (Leventhal et al., 1980) adapted to LBP (Bunzli et al., 2017).

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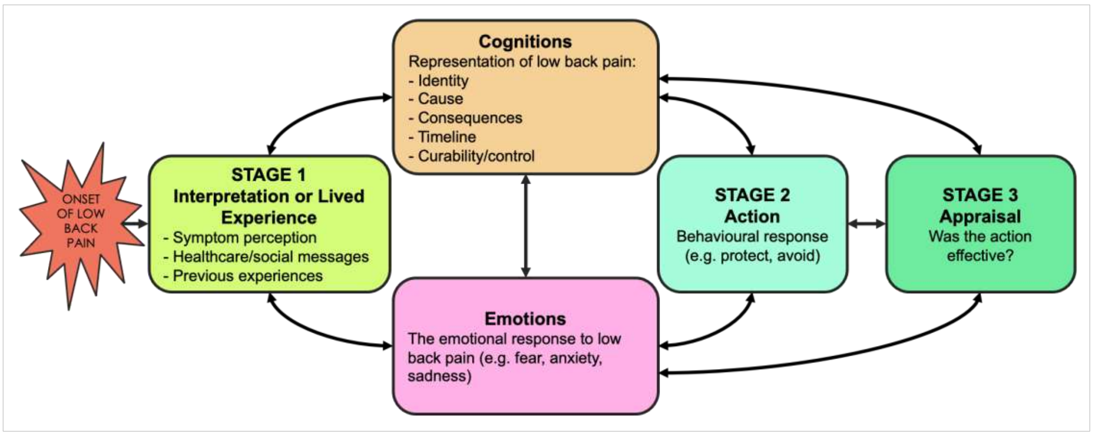

Emerging in the 1960s, the CSM has been widely used to explore how sense making processes influence coping and outcomes in a variety of chronic conditions such as osteoarthritis, heart disease, and diabetes (Broadbent et al., 2006; Leventhal et al., 1980; Moss-Morris et al., 2002; Nicholls et al., 2013). More recently, it has been applied in the LBP literature (O'Hagan et al., 2013; Siemonsma et al., 2013; van Wilgen et al., 2013).

The CSM suggests that when a person experiences LBP (stage 1), they attempt to make sense of it by forming a cognitive 'representation' based on existing beliefs that are grounded in their unique personal, social, and cultural contexts. This representation is made up of understanding what the pain is ('identity' beliefs), what caused the pain ('cause' beliefs), what consequences the pain has ('consequence' beliefs), how well the pain can be controlled ('control' beliefs), and how long the pain will last ('timeline' beliefs). A person's previous experiences of LBP (both direct and vicarious) influence their representation, as does information from sources such as the media, clinicians, and our own bodily sensations (Bunzli et al., 2017). Together, this information constantly updates the representation (Bunzli et al., 2017; Leventhal et al., 1980).

How a person with LBP interprets and represents their condition will also influence their emotional response to their symptoms and experiences (Leventhal et al., 1980). Symptoms perceived as unpredictable, uncontrollable or as having significant negative consequences are commonly perceived as a threat to a person's livelihood or homeostasis, frequently eliciting a fear response which may trigger more worry and rumination (Bunzli et al., 2017; Moss-Morris et al., 2002).

According to the CSM, a person's LBP-related cognitions and emotions influence what they do about it (the subsequent action, stage 2). Seen as a problem-based method of coping, the action is then *appraised* through a self-regulatory process (stage 3, appraisal) (Leventhal et al., 1980). This appraisal of whether the outcome of the action was effective or not feeds back into the cognitive representation and emotional response to guide future coping responses (Bunzli et al., 2017; Leventhal et al., 1980). This process is fluid, constantly updated, adaptable, and influenced by various multidimensional and contextual factors over time (Bunzli et al., 2017; Leventhal et al., 2016).

While the interpretations, cognitions, emotions, actions, and appraisals will likely differ between individuals and within individuals over time, the CSM suggests the processes involved in making sense of LBP remain the same (Petrie et al., 2007).

2.4.2 A case example: the Common Sense Model

Previous work demonstrates how the CSM can apply to people with persistent LBP (Bunzli et al., 2017; Caneiro et al., 2020). The below paragraphs briefly summarise a case example from Caneiro et al. (2020).

Jamie, a 41-year-old male, experienced severe LBP after lifting weights. He had previously experienced minor episodes of back pain from lifting that quickly recovered, but this episode was more severe and debilitating (stage 1: interpretation or lived experience). The limited ability to move and load his back without intense pain led him to belief that this time, he had done damage to his spine (cognitive representation: identity) from lifting (cognitive representation: cause). Jamie took time off work, rested, and avoid stressing his back (stage 2: action) as he believed this would protect his back from further damage (cognitive representation: control). At this stage, he was confident he'd recover (positive emotional response).

When his pain wasn't improving after a week (stage 3: appraisal), he began to worry (negative emotional response) about how serious the damage was (cognitive representation: identity) and that his pain may never go away (cognitive representation: timeline). He sought care from his doctor who prescribed him non-steroidal anti-inflammatory drugs, muscle relaxants, and opioids (stage 2: action). His doctor also sent him for a Magnetic Resonance Image (MRI) scan which showed disc degeneration and a disc bulge at L4/5, which his doctor explained as a worn out back that had been damaged (cognitive representation: identity) from weightlifting (cognitive representation: cause). His doctor recommended Jamie protected his back and not go to work (stage 2: action), which distressed Jamie and made him fearful of his future (negative emotional response). Jamie was referred to a physiotherapist who reinforced these messages, gave Jamie core exercises, and advised him to avoid lumbar flexion (cognitive representation: control) to protect his damaged back (cognitive representation: identify) and allow it to hopefully heal within 2 months (cognitive representation: timeline).

This case example demonstrates the complex, dynamic, and inter-related relationships between the experience of pain, societal and healthcare messages, cognitions, emotions, actions, and appraisals (Bunzli et al., 2017; Caneiro et al., 2020). While previously reported as a predominantly fear-based response (Vlaeyen et al., 2016), the CSM questions this (Bunzli et al., 2017). In the context of the symptoms, cognitions, and emotions exemplified in the case above, the avoidance of provocative tasks, or use of protective, careful, and guarded movements and postures, appears to be a reasonable *common sense* response.

Given the dominant social narrative of ‘protecting the (perceived) vulnerable spine’ (Bunzli et al., 2017) and common explicit advice from healthcare professionals to avoid certain movements if you have LBP (Darlow et al., 2015; Darlow et al., 2013; Darlow, Perry, Stanley, et al., 2014), the actions of ‘protect’ or ‘avoid’ seem valid and rational. While the protection or avoidance may be a helpful short-term response if there is an injury or specific pathology, in the context of non-specific LBP, avoiding tasks or performing them in protective and guarded ways may paradoxically increase pain (O’Sullivan et al., 2016). Pain may increase due to the loss of functional capacity or familiarity with the task, or because protective and guarded movements or postures may be pro-nociceptive (O’Sullivan et al., 2016). In addition to protective patterns potentially contributing to pain that can influence a person’s appraisals, cognitions, and emotions, it may be that protective movements and postures (conscious or nonconscious) contribute to the feelings of tightness, stiffness, and restriction commonly reported by people with LBP (Pugh & Williams, 2014), perpetuating the sense-making process underpinning their activity limitation.

While the CSM appears to be a useful framework for understanding the dynamic interplay between the numerous factors that can contribute to LBP, there is limited evidence investigating the relationship between movement, posture, and LBP through this lens. Case examples provide some indication of what this may look like, but in-depth investigations into how people conceptualise the link between movement, posture, and their LBP could provide further insights into this relationship.

2.4.3 Additional considerations

An additional consideration when understanding the relationship between movement, posture, and low back pain, and in particular the link between how an individual with LBP subjectively feels they move and how they objectively move, is that those two phenomena may not be the same. For example, Stanton et al. (2017) tried to understand whether ‘feeling back stiffness’ reflected objectively having a stiff back. The authors concluded that rather than reflecting biomechanical properties of the back, the feeling of ‘back stiffness’ is a protective perceptual construct that can be manipulated by providing auditory input (Stanton et al., 2017). This highlights that qualitative reports of movement or postural sensations (such as ‘feeling stiff’) may be a multisensory perceptual inference consistent with protection and might not necessarily be congruent with objective biomechanical measures.

2.4.4 Key points

What is known and not known about the models that attempt to understand how people understand their LBP?

- Almost all people with LBP consider movement and posture to be important, and the dominant narrative is one of 'protection' of (perceived) damaged or vulnerable spinal structures. People with LBP report these beliefs commonly come from encounters with healthcare practitioners, but the views are also common among society.
- The Common Sense Model (CSM) provides a useful model for understanding the rational cognitions, emotions, actions, and appraisals observed when people experience LBP, even when they may be counter-productive and not evidence-informed.
- There is limited research investigating the relationship between movement, posture, and LBP through the lens of the Common Sense Model.

2.5 Identifying the knowledge gap

Despite the high prevalence and large activity limitation associated with LBP (Hartvigsen et al., 2018; Vos et al., 2017), and the calls for research into LBP to be a priority area (Buchbinder et al., 2018; Carregaro et al., 2020) (including from the World Health Organisation (Kaplan et al., 2013)), much still remains unknown when considering the relationship between individualised movement, posture, pain, psychological factors, and activity limitation over time.

2.5.1 Individual-level investigation

One area of LBP research that remains understudied is research investigating the relationship between movement, posture, and LBP at an *individual person* level and using individualised assessments and treatments. Given the complex heterogeneity of LBP, individual-level methods may provide a useful approach to understanding the multifaceted relationships that likely vary widely between people with LBP (Kratochwill et al., 2012; Lillie et al., 2011).

A historical focus on cause and effect that is common among health science research (Kerry et al., 2012), has led to most of the existing literature that can provide insights into relationships between movement, posture, and LBP being derived from

RCTs. Typically, these studies do not tailor the assessment of movement or posture (Smith et al., 2014). Indeed, the Laird et al. (2012) and Steiger et al. (2012) systematic reviews that only included clinical trials with generic measures of movement are good examples of this. Not a single study in either systematic review assessed individually relevant movements (Laird et al., 2012; Steiger et al., 2012). The utilisation of individualised interventions was also uncommon.

While individualised assessment and intervention are two potential limiting factors, whether the *analysis* is at the individual level (as it was in the Steiger et al. (2012) review) may also be important. Analysis of individual level data (such as the correlation between changes on two clinical attributes) provides further insights into the presence of within-person relationships. An example of the opposite – analysis of group level data – is that while a group's mean bending velocity and mean activity limitation may both improve together (co-occur) and may be interpreted as being related, the people who improved in bending velocity may not be the same people who improved in activity limitation. An example of this can be observed in a study by Nordstoga et al. (2019), where kinematic measures were performed on 44 people with LBP over time and compared to pain and activity limitation measures. The authors found group-level data improvements in velocity and activity limitation (co-occurrence), but no relationship in individual-level data.

Similarly, if we had 100 people, and only 30% showed a relationship, then we'd conclude that, on average, there is no relationship. But this doesn't reflect the 30 people that *did* show a relationship. This is an example of the 'wash-out' effect, where the valid findings in a subgroup of patients are 'washed-out' by the valid but opposite findings in another subgroup (Dankaerts et al., 2009).

So, it appears there are many factors to consider when investigating relationships between movement, posture, and LBP. It is not known if the results of the two longitudinal systematic reviews would have been different if the studies they included had used individualised assessment and interventions. Despite large studies that use generic, one-size-fits-all approaches dominating the literature (Falla & Hodges, 2017) (presumably because they are easier to conduct and align with a historical focus on treatment efficacy and not relationships (Kerry et al., 2012)), it is possible for large studies to accommodate heterogeneity and individualisation, the RESTORE RCT is an example of this (Kent et al., 2019).

Another way of understanding the relevance of individual level assessment, treatment, and analysis is by asking the questions of: *is it useful to simply apply* *statistical averages from generic, homogenous measures to individuals who are different? Could starting from the assumption that everyone is different, and using tailored approaches yield additional useful insights?*

2.5.1.1 Are individualised interventions more efficacious?

While the potential importance of accommodating the measurement of individual movements and postures has been discussed in Section 2.2.3 above, and the potential relevance of individual-level analysis discussed in Section 2.5.1 above, this section discussed the potential relevance of individualised *interventions*.

Person-centred care has gained much attention in the research and clinical space (Borsook & Kalso, 2013; Lin et al., 2020; Lin et al., 2019; Tousignant-Laflamme et al., 2017). It has been reported that the 'one-size-fits-all' approach previously advocated by many guidelines may fail to target treatment of the specific factors that may be driving an individual's LBP (Foster et al., 2011; Savigny et al., 2009). Inadequately addressing the pertinent factors in an individual's LBP presentation may dilute treatment effects (Foster et al., 2011), which may further limit the ability to examine relationships between factors (the notion that 'if not much changes, it's hard to identify a change relationship').

Despite calls for individualised, person-centred care there is conflicting evidence showing significant benefit of such an approach. A recent RCT examining CFT, an individualised intervention targeting multidimensional contributing factors, has shown it to be more effective at reducing activity limitation (but not pain) at six and 12 months compared to a contemporary group-based multidimensional education and exercise intervention in 206 adults with persistent, disabling LBP (O'Keeffe et al., 2019). Effect sizes (95% CI) for activity limitation were 0.67 (0.27, 1.06) at six months, and 0.55 (0.18, 0.92) at 12 months (O'Keeffe et al., 2019), indicating moderate effects favouring the multidimensional individualised CFT (Cohen, 1988). Similarly, a RCT comparing CFT (multidimensional biopsychosocial individualisation) to manual therapy and exercise (physical/biological individualisation) found statistically and clinically significant between-group differences in pain and activity limitation reduction (Vibe Fersum et al., 2013; Vibe Fersum et al., 2019). Effect sizes (standardised mean differences - SMD) for activity limitation were 1.31 at three months, 0.72 at one year, and 0.70 at three years, while for pain they were 1.17 at three months, 0.59 at one year, and 0.25 (non-significant with the mean difference (95% CI) being -0.6 (-1.4, 0.3)) at three years (Vibe Fersum et al., 2019).

Similarly, stratified care has demonstrated superior effects in high-risk LBP populations presenting to general practices in England (Foster et al., 2014; Hill et al., 2011). However, a replication study adapted to Danish Primary Care failed to show any significant differences in clinical outcome, despite some indications stratified care may reduce healthcare costs (Morsø et al., 2021). There is also moderate quality evidence (based on GRADE assessment) that individualising treatment to match subjects' directional preferences based on the McKenzie approach (also known as Mechanical Diagnosis and Therapy – MDT) is significantly more effective at improving pain, activity limitation, and work participation compared to several un-matched comparison treatments based on the results of a systematic review including six RCTs (Surkitt et al., 2012). Similarly, when the core principles of MDT (assessment and treatment classification, and appropriate application of force) are followed, treatment effects appear to be greater (Halliday et al., 2019). Of note, effect sizes were small and of questionable clinical significance (Halliday et al., 2019), and the reliability of clinicians identifying aspects of the MDT assessment process are generally weak when following reliability reporting guidelines (kappa values all below 0.44, irrespective of levels of training) (Werneke et al., 2014), although reliability is infrequently considered (May et al., 2018). Further, when comparing MDT to other comparators (such as usual care, manipulative therapy, manual therapy, exercise, non-steroidal anti-inflammatory drugs, or education), there appears to be no clinically meaningful difference in outcomes (pain, activity limitation, or LBP recurrence) at any time points for people with acute or persistent LBP (Halliday et al., 2019; Karlsson et al., 2020; Lam et al., 2018).

The potential benefit of individualised care has also been reported in other body areas, where an individually tailored biopsychosocial intervention in a RCT of 122 people with musculoskeletal pain showed greater effects on reducing activity limitation compared to a dose matched, physical based exercise intervention (Asenlöf et al., 2005). Whether the significant reductions in outcomes using an individualised approach are worthwhile for health systems and patients though, remains unclear. This would involve comparing the cost-effectiveness of the approaches in terms of other healthcare use (such as opioid use, imaging, injections, or surgery), societal costs (return to work or sick leave), delivery costs, and considerations of patient preferences and intervention scalability (O'Keeffe et al., 2019).

In contrast, a systematic review of 14 RCTs comparing group and individual physiotherapy that incorporated exercise interventions found only small, clinically insignificant differences for pain and activity limitation outcomes on musculoskeletal conditions, questioning the utility of individualised approaches if they are more costly and yield similar outcomes (O'Keeffe et al., 2017). Results from the O'Keeffe et al. (2017) review support those of an earlier systematic review investigating targeted manual therapy or exercise that reported inconsistent, patchy, and underpowered trials, limiting the ability to make robust conclusions (Kent et al., 2010). Additionally, tailored exercises compared to general exercises in a RCT of 108 people with LBP classified as having movement control impairment found no additional benefit of specific exercises on activity limitation and pain (Saner et al., 2015). These results mimic an earlier study finding no difference between specific motor control training to generic graded activity in a RCT of 172 people with non-specific LBP (Macedo et al., 2012).

Further questioning the utility of individualised approaches, a RCT comparing treatment matched according to classification on the Movement System Impairment classification system (Sahrmann et al., 2017) to non-classification treatment in 101 people with persistent LBP found no difference in functional outcomes between the groups at six or 12 months (Van Dillen et al., 2016), with both groups demonstrating clinically important but similar long-term improvements. Interestingly, self-report subjective performance of movements and postures *did* have a unique, independent association to functional improvement (Van Dillen et al., 2016), suggesting a possible link between how well participants perceive they move and their change in function, however objective measures of movement were not collected, limiting this inference. Likewise, a RCT in 124 people with LBP greater than 12 months comparing matched treatments based on patient-specific clinical features to unmatched treatments found similar results (the authors used the Treatment-Based Classification (TBC) (Delitto et al., 1995) and the Movement System Impairment classification schemes (Henry et al., 2014)), with no difference in pain or activity limitation identified between matched and un-matched treatment immediately after the intervention period (six, weekly, one hour treatment sessions), or at 12 months (Henry et al., 2014). Conversely, older studies comparing matched to unmatched treatment approaches in people with LBP have demonstrated potentially clinically important differences using matched treatments (Brennan et al., 2006; Childs et al., 2004; Fritz et al., 2003), however, broad biopsychosocial factors known to influence clinical outcome (Lee et al., 2019; Lee et al., 2015; H. Lee et al., 2017) were not comprehensively considered. Further, older studies are often of lower methodological quality (Karlsson et al., 2020) and therefore potentially more prone to bias.

Notably, most of the studies that examined the influence of individualisation only individualised their care based on physical factors (such as signs and symptoms, responses to movement testing, or choice of physical treatment), and did not individualise care in a fully multidimensional biopsychosocial manner. There appears to be an indication that treatment approaches that *do* individualise care in a more multidimensional biopsychosocial manner are associated with identifying clinically meaningful differences (O'Keeffe et al., 2019; Vibe Fersum et al., 2013; Vibe Fersum et al., 2019). This may be because of those interventions' ability to accommodate a complex and heterogenous condition such as LBP (Hartvigsen et al., 2018).

In summary, individualisation according to the multidimensional variable factors present in people with LBP may enhance the treatment effect (the notion that outcomes can be optimised when interventions are targeted toward the right patients and tailored to address the specific clinically relevant attributes of each individual) (Falla & Hodges, 2017), but current evidence for this is limited. A greater change in pain or activity limitation may improve the ability to investigate whether changes in other factors (such as movement or posture) are related to that change in pain or activity limitation. If nothing changes (or our ability to create change is limited), investigating relationships between factors that change may be more difficult.

2.5.1.2 Influence of psychological factors may be heterogenous

Like the presence of movement and postural heterogeneity, the specific psychological factors that are clinically relevant may vary between individuals. Evidence discussed above in Section 2.3.1 relating to task specific but not general measures of pain-related fear predicting spinal movement ROM in people with LBP (Matheve et al., 2019), and individualised but not generic measures of kinesiophobia changing negatively following manual handling training (Horgan et al., 2020) lends some support to this position. Additionally, single-case experimental design studies that have measured psychological factors have shown variable baseline values among their participants, and variable patterns of change in these factors over time (Boersma et al., 2004; Caneiro et al., 2019; Simons et al., 2019), further supporting the presence of individually relevant psychological factors.

Despite this heterogeneity, there is limited evidence investigating how psychological factors are involved in the movement, posture, pain, and activity limitation relationship over time at the individual-level. With calls that LBP research should consider using specific and individualised measures of psychological and other multidimensional factors (Christe, Crombez, et al., 2021) and longitudinal designs (Wideman et al., 2013), the requirement for longitudinal individualised, multidimensional research is clear.

2.5.2 Qualitative approaches… patient voices matter!

"Personal pain experience is the starting point for the study of the meanings of pain" – Simon van Rysewick (van Rysewyk, 2016).

Research methods that focus on exploring personal narratives and perceptions can provide rich, meaningful, and clinically pertinent insights (Pincus 2010)(Bunzli et al., 2013). In addition to understanding the individual-level quantitative relationships between movement, posture, psychological factors, and LBP, a better insight into how individuals *conceptualise* this relationship may provide a richer, complementary, and more nuanced understanding (Queirós et al., 2017).

The growing representation of the voices of people with a lived experience is demonstrated by the rising emphasis to include patient, consumer, and community engagement throughout the research process (Belton et al., 2019), and the growing popularity of evidence derived using qualitative research methods (Collingridge & Gantt, 2008). Many qualitative methodological frameworks exist depending on the aims of the research and ontological worldview of the researchers. Common frameworks include Grounded Theory, Phenomenology, Ethnography, and Thematic Analysis (Braun & Clarke, 2020; Letts et al., 2007).

Nursing is an example of a health discipline that has enthusiastically endorsed qualitative methodology (Thorne et al., 1997). However, the domain of inquiry for health disciplines can be quite distinct from the methodological principles upon which traditional qualitative approaches are based. As such, the use of a non-categorical description that draws on the clinical expertise and insights of the researchers was developed by Thorne et al. (1997). This approach, called interpretive description, aims to describe a phenomenon in detail utilising the research team's expert knowledge about a condition to design, conduct, and interpret the research, thus extending current knowledge with significant clinical applicability (Thorne et al., 1997). Interpretive description integrates the individual experiences of the person experiencing the health condition with the research team's expertise of the condition to form credible, rigorous, and valid knowledge (Thorne et al., 1997; Thorne et al., 2004) and has been frequently used as a methodological framework in qualitative studies of people with LBP (Bunzli, McEvoy, et al., 2016; Darlow et al., 2015; Darlow et al., 2013; Miciak et al., 2019; Singh et al., 2018).

2.5.2.1 Qualitative studies about LBP

There is a substantial body of research using qualitative methodology investigating the lived experiences of people with LBP (Bunzli et al., 2013; Froud et al., 2014; Slade et al., 2014; Verbeek et al., 2004), the clinicians that treat LBP (R. Holopainen et al., 2020; Riikka Holopainen, Phoebe Simpson, et al., 2020; Pincus et al., 2006; Sanders et al., 2011; Synnott et al., 2015), and even some research investigating the experiences of the people who support those with LBP (McCluskey et al., 2014).

Comprehensively reviewing the entire qualitative literature relating to LBP is beyond the scope of this thesis. Briefly, findings from four systematic reviews of qualitative studies found that patients were concerned with the unique impact of LBP on their personal wellness, their ability to engage with meaningful activities, as well as how LBP influenced their societal role and identity (Bunzli et al., 2013; Froud et al., 2014; Slade et al., 2014; Verbeek et al., 2004). The importance of people with LBP having their pain validated was also common across the reviews. Similarly, a qualitative systematic review of 77 papers exploring the experiences of people with persistent non-malignant musculoskeletal pain identified key themes relating to an adversarial struggle to affirm self, reconstruct self in time, construct and explain their suffering, negotiate the healthcare system, and prove legitimacy (Toye et al., 2013). For some patients, there was also a sense of moving forward alongside the pain (Toye et al., 2013).

A qualitative synthesis of 25 cross-sectional studies involving 713 people with persistent LBP also detailed reports of a struggle, summarising the experience of persistent LBP as having your 'life on hold' (Bunzli et al., 2013). The three main themes that emerged from that synthesis were; a) the social construction of persistent LBP, b) the psychosocial impact of the nature of persistent LBP, and c) coping with persistent LBP (Bunzli et al., 2013). The authors conceptualised the experience of persistent LBP as a suspension of wellness, self, and future; and acknowledged that longitudinal research would allow better understanding of the influence of time on the persistent LBP experience (Bunzli et al., 2013).

When it comes to movement and posture, though, there is a distinct lack of qualitative literature that focusses on understanding the beliefs and experiences relating to movement and posture in people with LBP. Reports of stiff, tense, braced, restricted, and fearful movements and postures were found among the quotes of several qualitative papers (Bunzli, Smith, et al., 2016; Bunzli, Smith, Watkins, et al., 2015; Oosterhof et al., 2014; Pugh & Williams, 2014; Snelgrove et al., 2013), with these responses reportedly being in an effort to minimise further pain, damage, and functional loss (Bunzli, Smith, Watkins, et al., 2015), as discussed in Section 2.4. But no qualitative research with movement or posture as part of the research question could be found. While cross-sectional qualitative research investigating movement and posture appears scarce, longitudinal qualitative research about movement, posture, and LBP is even less common.

2.5.2.2 Longitudinal qualitative research about LBP

Existing research does not help us fully understand what it means to experience persistent LBP over time, or what recovery may look like. One retrospective qualitative study investigating people with persistent LBP who had undergone Cognitive Functional Therapy in Ireland and Australia identified two important themes for those who improved: changing pain beliefs, and achieving independence (Bunzli, McEvoy, et al., 2016). In that study, a progression from strong biomedical and structural pain beliefs to a more biopsychosocial perspective appeared to be a key requirement for a successful outcome (Bunzli, McEvoy, et al., 2016). This shift in pain beliefs was achieved through a strong therapeutic alliance, the development of body awareness, and the experience of control over pain during meaningful movement and activity (Bunzli, McEvoy, et al., 2016). For those that substantially improved, new problem-solving skills, higher self-efficacy, reduced pain-related fear, and improved stress coping helped them achieve independence (Bunzli, McEvoy, et al., 2016). But for those that were unchanged following CFT, a biomedical perspective was retained, they lacked pain control, and they continued to be defined by their pain (Bunzli, McEvoy, et al., 2016).

To help address the gap in understanding experiences of pain over time and what it means to recover from persistent pain, a recent meta-ethnographic synthesis of 195 qualitative studies aimed to explore the process of recovery (Toye et al., 2021). This meta-ethnographic synthesis was in *all* persistent non-malignant, musculoskeletal pain though, and not specifically LBP. While over three-quarters of people with persistent pain have pain in multiple body sites (of which the low back is often the most common) (Carnes et al., 2007), LBP can reportedly carry different societal consequences (Borkan et al., 1995; Froud et al., 2014). Nevertheless, Toye et al. (2021) found that validation and reconnection can empower a person with persistent pain to embark on a journey of healing. The authors reported that the healing journey takes commitment, energy, and support. Useful support from healthcare professionals focussed on validating a person’s pain through the careful listening of their unique story, through meaningful and acceptable explanations, and by encouraging connection to a meaningful sense of self, self-kindness, the exploration of new future possibilities, providing helpful strategies, and facilitating safe social reconnection (Toye et al., 2021).

While there were brief discussions about a renewed sense of confidence, a sense of relaxation, and the importance of being able to trust one’s ability to take care of themselves in the meta-ethnographic synthesis, there was no discussion relating to changes in movement or posture (Toye et al., 2021), highlighting the limited research in this area. Screening of the 195 included studies in the meta-ethnographic synthesis (Toye et al., 2021) revealed only one study that did discuss movement or posture in people with LBP (Pugh & Williams, 2014). The results of this retrospective qualitative study of 11 people with persistent LBP receiving Feldenkrais (a movement-based intervention) alluded to the importance of producing more efficient, effective, relaxed, and comfortable movements and postures (Pugh & Williams, 2014). These findings support a previous retrospective qualitative study in 36 people with LBP (some recovered, some unrecovered) exploring what LBP recovery means to them; with indications that being able to move freely and in a supple way were important (Hush et al., 2009).

From the perspective of pain-related cognitions and emotions, strong themes of shifting pain beliefs from a simple biomedical to a more wholistic biopsychosocial perspective were well supported in the qualitative meta-ethnographic synthesis, as were reductions in pain-related fear, pain catastrophising, and increased self-efficacy (Toye et al., 2021). These findings were congruent with those from the Bunzli et al. (2016) study. Additionally, the process of making sense of pain, which was another key theme in the meta synthesis, also supports the utility of the CSM in understanding persistent pain (Bunzli et al., 2017; Toye et al., 2021).

So, while there is a growing understanding of what it means to recover from persistent pain (Toye et al., 2021), there is little qualitative research investigating how people conceptualise the relationship between their movement and posture, and their

LBP, particularly how this conceptualisation changes as individuals improve (or not). Longitudinal designs, including the use of audio or quotes obtained from the first interview in the second interview to stimulate narratives and explore meanings (data prompted interviews) (Kwasnicka et al., 2015), will help provide unique insights into these conceptualisations.

2.5.3 Key Points

What are the gaps in understanding the relationship between movement, posture, and LBP over time?

- Existing research typically focussed on treatment efficacy, one-size-fits-all approaches, and designs with limited ability to accommodate relationships that are likely heterogenous.

- Despite substantial cross-sectional qualitative research into the lived experiences of people with LBP, there is limited research investigating how people with LBP conceptualise the link between movement, posture, and LBP, particularly longitudinally as they improve.

2.6 Methodology and technology available to better understand the relationship between movement, posture, and LBP

Despite the substantial investment into researching LBP, activity limitation and costs continue to rise (Buchbinder et al., 2020; Deyo et al., 2009; Hartvigsen et al., 2018). While ‘big data’ appears to hold some promise in further understanding and improving LBP, there is increasing recognition for alternative designs, such as single-case designs, to develop knowledge (van Rysewyk, 2016).

2.6.1 Single-case designs

Single-case designs are intensive, prospective, and controlled studies of individuals using each person as their own control (Morley, 2018; Tate, Perdices, Rosenkoetter, McDonald, et al., 2016). They are particularly well suited to understanding when, how, and under what conditions changes to multiple, individualised factors occur (Borckardt et al., 2008). Frequently used in behavioural sciences, single-case designs (also referred to as N-of-1 trials in medicine) provide a strong level of evidence when designed and conducted well, particularly at the individual level (Kratochwill et al., 2012; Lillie et al., 2011; Tate, Perdices, Rosenkoetter, McDonald, et al., 2016). With their popularity growing, the methodological complexity and the sophistication in the analysis of single-case data has also rapidly increased (Tate, Perdices, Rosenkoetter, McDonald, et al., 2016).

Single-case designs are characterised by a baseline control phase (also known as an ‘A phase’) where repeated (usually at least five) measures of key variables of interest take place (Morley, 2018; Tate, Perdices, Rosenkoetter, McDonald, et al., 2016). This phase is typically used to demonstrate that the outcome of interest has a relatively stable behaviour over a period that precedes the second phase, the treatment phase (also known as the ‘B phase’). The key variables of interest continue to be measured repeatedly and frequently during the treatment phase, as they do in any subsequent phase (Kratochwill et al., 2012; Tate, Perdices, Rosenkoetter, McDonald, et al., 2016). Following the treatment phase, a second control phase (also known as an A or A’ phase, depending on whether the treatment effect is expected to carryover) takes place (Kratochwill et al., 2012). This can be followed by several more phase changes (for example ABAB) forming a common ‘withdrawal/reversal’ design (Kratochwill et al., 2012; Tate et al., 2013).

Single-case designs that exercise careful experimental control (for example through randomisation, multiple-baselines, alternating treatments, or changing criterion designs) are termed single-case *experimental* designs (SCEDs) (Tate et al., 2013). Previously absent from standard levels of evidence tables, SCEDs such as the randomised n-of-1 trial are now considered Level 1 evidence for treatment benefits and harms by the Oxford Centre for Evidence-Based Medicine, a position they share with systematic reviews of RCTs (Howick et al., 2011).

A key advantage of single-case designs over RCTs, lies in the repeated measures of data that is adaptable and individualised according to the specific presentation of the person being studied (Tate et al., 2013). Further, the measurement of *multiple* different factors that may relate to a person’s presentation allows for the investigation of relationships between factors that may interplay in different ways for different people overtime (Borckardt, 2008; Morley, 2018; Vlaeyen et al., 2012). These relationships can then be analysed visually and statistically (Borckardt, 2008; Kratochwill et al., 2012). So, while providing a complementary (rather than replacement) design in the process of building evidence, single-case designs are well placed to provide further understanding of the individualised relationships between movement, posture, psychological factors, pain, and activity limitation in people with

LBP (Borckardt, 2008; Kratochwill et al., 2010; Tate, Perdices, Rosenkoetter, McDonald, et al., 2016).

Single-case designs have demonstrated useful applicability when investigating the multiple, interacting relationships between LBP, activity limitation, cognitive factors, emotional factors, and behaviours. Further, they have been used to generate hypotheses about potential mechanisms and explore various treatment approaches. Examples include investigating the utility of graded exposure in people with LBP (Boersma et al., 2004; Simons et al., 2019; Vlaeyen et al., 2001) and understanding the process of change in people with LBP and high pain-related fear (Caneiro et al., 2019). While these papers provide valuable insights into the complex and variable relationships between multiple factors, all these factors were self-report and subjective. That is, while *reports* of fear of movement or avoidance may have improved, there were no objective measures of movement or activities that confirmed or rejected that subjective perception. With the utility of modern, wireless, wearable sensors to frequently and efficiently measure movement, posture, or activities, single-case designs provide viable and promising options to integrate individualised objective and subjective measures, allowing the investigation of relationships between these factors (Lillie et al., 2011). This is especially true given the aforementioned contemporary focus on individualised care (Lillie et al., 2011; Lin et al., 2020).

2.6.2 Measuring movement and posture

Traditionally, biomechanical parameters of movement and posture have been measured using precise but expensive and cumbersome laboratory-based three-dimensional (3D) motion analysis and intramuscular EMG tools that require significant technical expertise (Cuesta-Vargas et al., 2010; Perry et al., 1981). However, emerging technologies in the form of wearable inertial measurement units (IMUs) and surface EMG (sEMG) sensors offer new possibilities in measuring movement and posture.

Wearable sensors offer a highly portable and user-friendly alternative to measure movement, posture, and muscle activity; with clinically acceptable accuracy, technical reliability, and reproducibility (Charry et al., 2011; Dobkin, 2013; Fong & Chan, 2010; Giroux & Lamontagne, 1990; Haines & Bowles, 2017; Lillie et al., 2011; Mjosund et al., 2017; Ronchi et al., 2008; Tao et al., 2012). Their small size minimises their intrusiveness for the person wearing them and allows the repeated capture of movement and posture in a comfortable, naturalistic manner in settings external to a motion analysis laboratory (such as the clinical setting) (Kent et al., 2015; Lillie et al., 2011). While presenting promising alternatives to measure movement and posture, wearable sensors also present some limitations as highlighted in a 2017 systematic review of wearable technology for spinal movement assessment (Papi et al., 2017). These include the calibration and data filtering requirements that add to data processing time. Additionally, the influence of drift errors when integrating acceleration and angular velocity signals, the influence of magnetic fields on magnetometers, and the limited ability to integrate and measure multi-planar movement present further limitations. Similarly, errors relating to sensor positioning or skin movement artefact and misalignment between sensor axes and underlying anatomical segments are additional considerations (Papi et al., 2017). While some of these limitations are unique to wearable sensors, others (such as movement artefacts) are limitations that exist in traditional technology that measures movement and posture using skin-based devices whether portable or not (Papi et al., 2017). Despite these considerations, differences of as little as one to three degrees have been reported in the sagittal and coronal plane during spinal movement compared with gold standard measurement systems (Mjosund et al., 2017).

The position of the wearable sensors depends on the device but is typically on, or above and below, the area being measured. The wearable sensors are usually held in place using hypo-allergenic adhesive. For measuring spinal movement, the IMU's are usually placed on the lower thoracic spine (T12) and the upper sacrum (S2), while the sEMG sensors are commonly placed bilaterally over the erector spinae two centimetres lateral to the third lumbar spinous process (L3) (Kent et al., 2015; Laird et al., 2019).

So, in summary, wearable sensors provide a useful way to capture repeated measures of person-specific movements and postures in a naturalistic and acceptably accurate way in the clinical setting.

2.6.2.1 Interventions to create change and allow longitudinal investigations into the relationship between movement, posture, and LBP

Despite the array of treatments available for LBP (Haldeman & Dagenais, 2008), most treatments show small to moderate effects on average, with little evidence of superior approaches (Hayden et al., 2005; Keller et al., 2007; Machado et al., 2009). Indeed, there is a "dire need for developing more effective interventions" (p1776)(Keller et al., 2007). To investigate the longitudinal relationship between changes in movement or posture, and changes in pain or activity limitation in people with LBP, there needs to be some form of 'perturbation' that substantially affects these factors.

Individualised approaches have been proposed as potentially providing more efficacious alternatives to historical one-size-fits-all approaches (Falla & Hodges, 2017). They have gained much attention and align with the consistent recommendations from 11 high-quality clinical practice guidelines (Lin et al., 2020; Lin et al., 2019), but, as discussed in Section 2.5.1.1 above, are yet to demonstrate consistently superior results.

2.6.2.1.1 Cognitive Functional Therapy

One individualised approach showing promising results is Cognitive Functional Therapy. Cognitive Functional Therapy is a physiotherapy-led, psychologically informed, integrated behavioural approach for the management of LBP after serious and specific pathology has been excluded (O'Sullivan et al., 2018). Aligned to contemporary guidelines, CFT targets modifiable psychological and physical barriers of recovery in the context of the biopsychosocial model (Lin et al., 2020; Lin et al., 2019; Maher et al., 2017; O'Sullivan et al., 2018). It addresses individually relevant movements and postures identified as provocative for the person, as well as the cognitive and emotional factors that underpin them (O'Sullivan et al., 2018). CFT has shown large and sustained results particularly in the reduction of activity limitation (for example SMD of 0.72 compared to manual therapy and exercise at 12 months, and 0.70 at three years for activity limitation (Vibe Fersum et al., 2019)) (Ng et al., 2015; O'Keeffe et al., 2019; O'Sullivan et al., 2015; Ussing et al., 2020; Vaegter et al., 2019; Vibe Fersum et al., 2013). As CFT also targets relevant movement, postural, and psychological factors, it provides a useful tool to create change and therefore investigate the interplay between these factors over time.

2.6.3 Key points

Methods to research and measure the relationship between movement, posture, and LBP from an individual perspective.

- Single-case designs provide a useful method to repeatedly measure multiple salient, person-specific factors and compare the interplay between these factors before, during, and after an intervention, providing a useful tool to investigate relationships between multiple factors in heterogenous conditions over time.

- Wearable wireless sensors that measure movement, posture, and muscle activity in accurate and ecologically valid ways allow for the frequent capture of individualised movements and postures in a naturalistic way.

- Cognitive Functional Therapy (CFT), an individualised, biopsychosocial approach, provides a useful tool to create change in LBP outcomes, allowing the longitudinal investigation of relationships between movement, posture, and LBP.

2.7 Summary of existing literature

Low back pain is the most disabling health condition globally and is associated with enormous individual and economic burden. People with LBP commonly believe that their pain means their back is damaged or injured - that something is wrong with their structure. These biomedical beliefs (that are often erroneous) appear to be reinforced by healthcare professionals despite evidence suggesting that no specific structural cause can be identified in approximately 90% of people with LBP. The contemporary understanding of LBP is that it is a condition influenced by complex interplays between numerous multidimensional biopsychosocial factors that can vary between and within people over time. Two factors widely believed to relate to LBP are movement and posture.

Most people with or without LBP believe that maintaining ‘good’ posture and moving ‘correctly’ are important for its prevention and treatment. Beliefs such as ‘keep your back straight’, ‘sit and stand up tall’, ‘don’t slouch’, ‘bend your knees when you lift’, and ‘brace your core’ are commonplace amongst society, including those with LBP and clinicians. And when measuring movement and posture during commonly problematic tasks such as bending, lifting, sitting, and standing, on average, people with LBP embody these beliefs. They display reduced spinal range, slower movement, and increased muscle activity, demonstrating a more guarded and protective strategy. This protective strategy could be viewed as a common sense response to beliefs of a damaged spine. But following rehabilitation, current research suggests that, on average, improvements in pain and function appear largely *unrelated* to changes in movement or posture. In other words, LBP improvement does not appear to be related to movement or posture ‘getting better’.

In the context of movement and postural heterogeneity (different movements and postures being clinically important for different people), current methods that measure and average common factors for all participants may overlook valuable insights into person-specific relationships. Other variables, such as pain-related cognitions and emotions (psychological factors), are also known to influence movement and LBP outcomes. For example, the more pain-related fear or pain catastrophising a person with LBP has, the more likely they are to demonstrate a more protective pattern (reduced spinal range and increased muscle activity). While this relationship appears consistent and irrespective of pain intensity, the association across groups of people with LBP is weak, and more individualised measures of psychological factors, movement, and posture have been recommended.

In addition to the limited understanding of the individual-level relationship between changes in movement, posture, psychological factors, and LBP, how the *conceptualisation* of movement and posture changes following rehabilitation in people with a lived experience of persistent, disabling LBP remains largely unknown. Qualitative data captured before and after rehabilitation can provide rich knowledge into how this conceptualisation changes in people with LBP. Investigating this under the framework of the Common Sense Model appears potentially helpful in understanding the cognitions, emotions, actions, and appraisals that accompany the LBP experience, especially through the lens of the individual.

The growing push for person-centred and individualised healthcare has seen a corresponding appreciation of individual-level research methods as limitations of large, group-level approaches become apparent. Rigorous and well-conducted single-case designs provide a useful and complementary tool for understanding relationships between multiple individualised factors in complex heterogeneous conditions such as LBP. Their ability to accommodate the assessment of individually relevant movement and posture using emerging technologies such as ecologically valid wearable sensors, as well as accommodate individualised treatment approaches such as Cognitive Functional Therapy, means they are well-positioned to provide clinically relevant insights, especially when combined with qualitative interviews.

2.8 Aims of thesis

1. Systematically review the *cohort study* and *RCT* literature to investigate how frequently within-person changes in spinal movement relate to changes in pain or activity limitation, including the direction movement changes as LBP improves.

2. Systematically review the *single-case design* literature to investigate how frequently within-person changes in spinal movement relate to changes in pain or activity limitation, including the direction movement changes as LBP improves.

3. Investigate the relationship between changes in individually relevant spinal movement and posture, and changes in pain or activity limitation using a replicated, repeated measures single-case series of 12 people with persistent, disabling LBP undergoing a 12- week Cognitive Functional Therapy intervention.

4. To understand how 12 people with persistent, disabling LBP *conceptualise* the relationship between movement, posture, psychological factors, and their LBP, before and after a 12-week Cognitive Functional Therapy intervention, integrating qualitative findings with individualised quantitative measures of movement, posture, psychological factors, pain and activity limitation.

2.9 Significance of thesis

This body of research explored the legitimacy of beliefs at the core of LBP research, clinical practice, and the health industry that are accepted as factual among society. Despite an almost universal belief that movement and posture relate to LBP, we know surprisingly little about this at the individual level, particularly over time. Utilising an individualised, mixed-methods approach that is well suited to the heterogeneity of LBP, this work aims to provide useful insights into whether changes in person-specific movement or posture relate to changes in pain or activity limitation, how movement and posture change when LBP improves, and the perspectives of how people with a lived experience of LBP conceptualise this relationship following recovery.

Developing an understanding about the strength, prevalence, and type of relationships between individualised movement, posture, psychological factors, and LBP over time will help provide important considerations in the management and prevention of LBP. Individual-level investigations complemented by qualitative findings from people with a lived experience of LBP will also give voice to the perspective of the people clinicians see in their treatment rooms every day, the individual.

Chapter 3 Systematic review: Cohort studies and RCTs

Does Movement Change When Low Back Pain Changes? A Systematic Review

Existing systematic reviews suggest that changes in movement are infrequently related to changes in pain or activity limitation. However, there are numerous factors that may influence the identification of a relationship; namely the use of individual-level data (such as correlation analyses), the ability to individualise movement assessment and intervention approaches, and the diversity of movement parameters measured.

This chapter presents a systematic review of group-level studies that aimed to investigate how frequently *changes* in diverse movement parameters relate to *changes* in low back pain and activity limitation at the individual-level, including the types of change in movement that occur when a relationship is identified. This review was published in the *Journal of Orthopaedic & Sports Physical Therapy (JOSPT)* and will be presented in its published format. Additional dissemination and knowledge translation materials are presented in Thesis Appendix A.1.1.

This chapter was published in the *Journal of Orthopaedic & Sports Physical Therapy*

Wernli, K., Tan, J., O'Sullivan, P., Smith, A., Campbell, A., & Kent, P. (2020).

Does movement change when low back pain changes? A systematic review. Journal of Orthopaedic & Sports Physical Therapy, 50(12), 664-670. *https://doi.org/10.2519/jospt.2020.9635*

3.1 Abstract

Objective: To investigate the relationship between changes in volitional spinal movement (including muscle activity) and changes in pain or activity limitation at the individual level in people with nonspecific low back pain.

Design: Etiology systematic review.

Literature Search: MEDLINE, Embase, CINAHL, and AMED were searched from inception to January 2020.

Study Selection Criteria: The study included peer-reviewed articles that reported the relationship between changes in volitional spinal movement and changes in pain or activity limitation at the individual level in people with nonspecific low back pain.

Data Synthesis: The data were descriptively synthesized to identify a relationship between change in movement and improved pain or activity limitation.

Results: We included 27 studies involving 2,739 participants. There was low-quality evidence of a relationship between change in movement and change in pain or activity limitation at the individual level 31% of the time (20 of the 65 times investigated within the 27 studies). Increases in spinal range of motion, velocity, and flexion relaxation of the back extensors were consistently related to improved pain or activity limitation (93%, 18.5/20 relationships observed).

Conclusion: A relationship between changes in movement and changes in pain or activity limitation was infrequently observed at the individual level; however, a paucity of high-quality evidence precludes a definitive understanding of this relationship.

3.2 Introduction

[LITERATURE REVIEW]

KEVIN WERNLI, PT[1,2] • JAY-SHIAN TAN, PT, MSc[1] • PETER O'SULLIVAN, PT, PhD[1,2]
ANNE SMITH, PT, PhD[1] • AMITY CAMPBELL, PhD[1] • PETER KENT, PT, DC, PhD[1,3]

Does Movement Change When Low Back Pain Changes? A Systematic Review

Low back pain (LBP), the most burdensome nonfatal health condition,[16,17] is highly prevalent[14] and expected to have an increasing impact.[3] Nonspecific low back pain (NSLBP) describes back pain where no definitive pathoanatomical cause can be determined, which is approximately 90% of the time.[28,37]

Patients, clinicians, and researchers frequently believe that the way a person moves may influence the likelihood of developing and recovering from NSLBP.[26,34,36] Movement interventions[26] are predicated on effecting a change in movement to improve back pain. Slower movements with less multiplane range of motion (ROM), less variability, increased stiffness, and altered patterns of trunk muscle activity characterize people with NSLBP.[13,22,29,31,44,52,67] However, it is unclear whether changes in the way people with NSLBP move are related to changes in pain and activity limitation.

Concurrent changes in lumbopelvic movement and improvements in pain or activity limitation are infrequent.[32] However, previous research has typically evaluated group-level change; therefore, it is unclear whether the people who changed their movement were also those who had a change in pain or activity limitation (individual-level change). Conclusions based on group-level results can be different from those based on individual-level results.[23,41,54] A systematic review of individual-level data only found a relationship between changes in spinal flexion, lateral flexion, and rotation ROM and changes in pain or activity limitation in 1 in every 3 (6.5/19) of the associations investigated.[64]

Current research does not support the deeply held belief of a relationship between changes in the way someone moves and a change in back pain, although movement parameters (ie, velocity and muscle activity) have not been comprehensively investigated.

Thus, (1) synthesizing data from studies that measure individual-level changes in both movement and pain or activity limitation over time, and (2) data that include diverse movement parameters (such as movements in additional planes, lumbopelvic patterns, velocity and muscle activity parameters) may help to clarify the relationship between changes in movement and changes in pain or activity limitation at the individual level.

Therefore, the aim of our review was to determine whether there was a relationship between changes in volitional spinal movement (lumbopelvic kinematics, lumbar flexion/extension angle, lumbar flexion during functional tasks, lumbar

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STUDY SELECTION CRITERIA: The study included peer-reviewed articles that reported the relationship between changes in volitional spinal movement and changes in pain or activity limitation at the individual level in people with nonspecific low back pain.

DATA SYNTHESIS: The data were descriptively synthesized to identify a relationship between change in movement and improved pain or activity limitation.

RESULTS: We included 27 studies involving 2739 participants. There was low-quality evidence of a relationship between change in movement and change in pain or activity limitation at the individual level 31% of the time (20 of the 65 times investigated within the 27 studies). Increases in spinal range of motion, velocity, and flexion relaxation of the back extensors were consistently related to improved pain or activity limitation (93%, 18.5/20 relationships observed).

CONCLUSION: A relationship between changes in movement and changes in pain or activity limitation was infrequently observed at the individual level; however, a paucity of high-quality evidence precludes a definitive understanding of this relationship. *J Orthop Sports Phys Ther 2020;50(12):664-680. Epub 28 Oct 2020. doi:10.2519/jospt.2020.9635*

KEY WORDS: *exercise therapy, low back pain, movement, physical therapy, systematic review*

[1]School of Physiotherapy and Exercise Science, Curtin University, Bentley, Australia. [2]Body Logic Physiotherapy, Shenton Park, Australia. [3]Department of Sports Science and Clinical Biomechanics, University of Southern Denmark, Odense, Denmark. This review was registered with PROSPERO (CRD42017064436). An Australian Government Research Training Program Scholarship was received by Kevin Wernli to support his capacity to undertake this research. The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article. Address correspondence to Kevin Wernli, School of Physiotherapy and Exercise Science, Curtin University, Kent Street, Bentley, WA 6102 Australia. E-mail: kevin.wernli@postgrad.curtin.edu.au

3.3 Methods

contribution to flexion, velocity and timing of lumbar kinematics, flexion relaxation, lumbopelvic muscle activity) and changes in pain or activity limitation at the individual level in people with NSLBP.

METHODS

THE PRISMA STATEMENT[50] WAS FOLLOWED for reporting items in this prospectively registered systematic review (PROSPERO registration: CRD42017064436).

Identifying and Selecting Studies for Review

Information Sources The electronic databases from MEDLINE, Embase, CINAHL, and AMED were searched from inception to August 21, 2017. An updated literature search was performed on January 8, 2020. Reference lists of retrieved articles were screened.

Search Our comprehensive search strategy was adapted from a previous systematic review.[32] We used medical subheadings and key words that encompassed the themes of changes in movement and changes in pain and activity limitation in people with NSLBP (see **APPENDIX A** for the search strategy used in the MEDLINE database). Our search strategy was developed in collaboration with a university faculty librarian. The strategy included 2 previous systematic reviews in the field[32,64] that were also assessed.

Selection Criteria We included studies of the relationship between changes in volitional spinal movement and changes in either pain or activity limitation at the individual level in people with NSLBP. Low back pain was defined as pain between the 12th thoracic vertebra and gluteal folds. There was no restriction on the duration of LBP. Interventions had to be nonsurgical and nonpharmacological, but could be cognitive, behavioral, physical, or of a combined nature targeting the body and/or mind.

We excluded studies that included pregnant women or people who had a specific pathological cause for their back pain (such as spinal malignancy, infection, fracture, cauda equina syndrome, metabolic or spinal inflammatory disorders, or nerve compression). Studies had to be written in English, and participants had to be older than 12 years of age.

Study Selection We used Covidence systematic review software (Veritas Health Innovation Ltd, Melbourne, Australia) to manage study selection. Following the removal of duplicates, eligibility assessment was performed on a standardized form independently by 2 reviewers (K.W. and J.T.), who were blinded to each other's assessments. Conflicting assessments were resolved by discussion or by a third reviewer (P.K.) when consensus could not be reached. Titles and abstracts, as well as full-text versions of the included studies, were screened using the same procedures.

Quality Assessment

Risk of Bias Within Individual Studies Our aim was to determine the prevalence of statistical associations between change in one patient characteristic and change in another. The sources of bias relevant to questions about these characteristics, treatments, and etiologies overlap but are not identical. Although all participants included in our systematic review received treatment, treatment exposure was not relevant to our research question. The included studies estimated the strength of a relationship between change in movement and change in pain or activity limitation. Due to heterogeneity of movement parameters, measurement tools, interventions, and analysis techniques in the included studies, we could not pool the data. Instead, we used vote counting to report the prevalence of a significant relationship across the included studies; therefore, some sources of bias were different.

The most important sources of bias in our systematic review were related to how well the population was described (generalizability of the findings), the validity and reliability of the method of measurement of the variables, the missingness of data, the appropriateness of the statistical analysis, and assessor blinding. We adapted the Joanna Briggs Institute critical appraisal checklist for cohort studies[51] to reflect these sources of bias (**APPENDIX B**). While no psychometric data are available specifically for this tool, the original checklist for cohort studies was extensively peer reviewed,[51] and a similar tool has satisfactory validity.[53]

We pilot tested and adapted the tool before 2 reviewers (K.W. and J.T.) independently assessed each study included in our systematic review. Conflicting assessments were resolved by discussion or by a third reviewer (P.K.) when consensus could not be reached. The independent ratings of the 2 reviewers had a percentage agreement across the 9 assessment items of 92.3% to 100.0% (median, 96.2%; interquartile range, 2.9%).

Studies that scored positively on all checklist items had a low risk of bias. Because the most critical risks of bias for our research question were related to the validity and reliability of the method of measurement of the 2 variables, the appropriateness of the statistical analysis, and assessor blinding, we categorized studies as having a medium risk of bias when they scored positively on all those items and negatively or were unclear on noncritical risks. A study was at high risk of bias when any of the critical-risk items were scored negatively or were unclear.

Quality of Evidence Across Studies We used the Grading of Recommendations Assessment, Development and Evaluation (GRADE) tool[18] to rate the overall quality of evidence across the studies. Risk of bias, imprecision, inconsistency, indirectness, and publication bias were assessed relative to our research question about the presence of a relationship between change in movement and change in pain or activity limitation. Randomized controlled trials (RCTs) were analyzed as cohort studies, because treatment allocation was not relevant to our research question. The GRADE guidelines suggest starting at "medium quality" for research

3.4 Results

using cohort designs. We used the other GRADE criteria to upgrade or downgrade the quality score (further detail on our application of the GRADE tool can be found in **APPENDIX C**).

Data Analysis

Data-Collection Process and Data Items A data-extraction table was pilot tested on 4 studies and refined to improve efficiency in collecting key outcomes related to our research question. Subsequently, greater emphasis was placed on extracting details of the movement and pain and activity limitation measures, so that their validity and reliability could be better evaluated. For all included papers, 2 reviewers (K.W. and J.T.) independently extracted the following data: (1) study design, (2) participant characteristics, (3) sample size, (4) intervention (including type, dosage, duration, and frequency), (5) movement parameters, their change, and method of measurement, (6) clinical outcome (pain or activity limitation), its change, and method of measurement, and (7) statistical analysis method and results about the relationship between changes in movement and changes in outcome (if available). Conflicts were resolved by discussion and, when consensus could not be reached, a third reviewer (P.K.) was consulted. Three authors[6,11,60] were contacted via e-mail for further information but did not respond.

Types of Movement Measures Volitional spinal movement measures encompassing either spinal kinematic or muscle activity parameters that were objectively quantified using an instrumented technique were included. Acceptable measures included (1) lumbopelvic kinematics (eg, lumbar flexion/extension angle, lumbar flexion ROM during functional tasks, lumbar contribution to flexion, velocity and timing of lumbar kinematics) and (2) muscle activation (eg, the flexion-relaxation phenomenon, lumbopelvic muscle activity during volitional spinal movement). The flexion-relaxation phenomenon refers to the electrical "silence" (relaxation) of the paraspinal muscles when an individual reaches end-range flexion.[70] This period of relaxation is frequently absent in individuals with back pain, and a flexion-relaxation ratio (largest in people without LBP) has been developed to standardize reporting of the flexion-relaxation phenomenon.[70]

Measures were defined as representing lumbar ROM if the calculation was derived from a lower thoracic or upper lumbar region relative to a pelvic segment; otherwise, they were classified as multisegmental measures. Parameters related to measures not including volitional spinal movement (such as gait, proprioception, muscle timing and cross-sectional area during static positions, or feedforward onset in response to alternate limb movement) were excluded.

Timing of Measurement Movements had to be measured at a minimum of 2 time points to obtain a measure of change. If multiple time points were reported (eg, postintervention and 3- and 12-month follow-ups), the time point closest to the end of the intervention period was extracted.

Primary Measure The primary measure determined the presence of a relationship between a change in movement and a change in pain or activity limitation at the individual level. In addition to the presence of a relationship, we also investigated the direction of the relationship, for example, whether an increase or decrease in movement ROM, velocity, or flexion relaxation was related to improved pain or activity limitation. We also combined the pain and activity limitation data into one outcome to provide a supplementary, broader summary of the relationship between changes in movement and changes in outcome.

Synthesis of Results

A descriptive synthesis was undertaken, with a sensitivity analysis planned based on the risk of bias of the individual studies.

We used a vote-counting system to summarize how frequently a relationship was observed. Each movement parameter was assigned 1 vote (value of 1.0) when a relationship was found between the parameter and pain or activity limitation. For studies that used multiple measures for a single movement parameter (eg, measuring flexion with both a modified-modified Schober test and through rachimetry with computer analysis[10]), the vote was divided by the total number of measures used.

People with high levels of pain and activity limitation may have a greater capacity to change their pain or activity limitation and, in turn, may be more likely to show a relationship with concomitant changes in movement. Therefore, as an additional analysis, we assessed whether (1) baseline levels of pain and activity limitation were comparable to those in published NSLBP trials, and (2) mean baseline levels of pain and activity limitation were comparable in studies that did and did not identify a relationship with flexion-related movement, the most common movement investigated. All pain and activity limitation values were transformed to a 0-to-100 scale (higher scores are worse). If a study reported multiple flexion parameters, that study was only counted once in each group (either it did or did not show a relationship) to avoid counting the same participants more than once (to preclude bias toward studies that measured multiple flexion parameters).

RESULTS

THE SEARCH IDENTIFIED 3920 ARticles, of which 1104 were duplicates; therefore, we assessed 2816 articles for eligibility. The reasons for exclusion are presented in the PRISMA flow diagram (**FIGURE 1**).

Characteristics of Included Studies

We included 27 studies[2,6,9-12,19,23,24,35,38-42,45-47,49,54,59-62,66,69,73] (n = 2739 participants). Seven studies[24,35,38-40,49,60] used data from an RCT. The details of individual studies are presented in **APPENDIX D** (available at www.jospt.org), while **TABLE 1** presents summaries related to sample size, measurement tools, and time between measurements for each movement parameter.

Table 3.1 Movement characteristics. Systematic review: Cohort studies and RCTs

TABLE 1 CHARACTERISTICS FOR EACH MOVEMENT TASK

Movement Category	Movement Parameter/ Measurement Type	Sample Size, n	Measurement Tools (n Studies)	Pain/Activity Limitation Measurement Tools (n Studies)	Time Between Measurements, wk
Flexion	Flexion ROM (peak)				
	Lumbar[6,10,19,23,40,47,55,62,66]	Range, 21-456; median, 89; IQR, 79.5[a]	Inclinometer or goniometer (5), electromechanical (2), motion sensor (1), Schober test (1)	Pain: VAS (2), NPRS (2) Activity limitation: RMDQ (2), ODI (3), PSFS (1), QBPDS (1), HFQ (1), LBP Disability Index (1)	Range, 3-12; median, 6.5; IQR, 5[a]
	Multisegment[9-11,38,54,60,62,66]	Range, 17-111; median, 38.5; IQR, 41.2[a]	Fingertip to floor (4), motion sensor (2), electromechanical (1), rachimetry (1)	Pain: NPRS (2), VAS (1) Activity limitation: RMDQ (4), ODI (3), HFQ (1)	Range, 4-38; median, 9; IQR, 4.5[a]
	Flexion sEMG variables				
	Lumbar[41,55,61,62,69,73]	Range, 18-68; median, 34.5; IQR, 24[a]	sEMG (flexion relaxation of lumbar paraspinal muscles) (6)	Pain: NPRS (2), VAS (3) Activity limitation: ODI (3), RMDQ (1)	Range, 1-12; median, 5.5; IQR, 4[a]
	Flexion velocity and rhythm				
	Lumbar[62]	33 (only 1 study)	Motion sensor	Did not measure pain Activity limitation: ODI	8 (only 1 study)
	Multisegment[54,60,62]	Range, 33-111; median, 44; IQR, 78[a]	Motion sensor (2), electromechanical (1)	Pain: NRS (1) Activity limitation: ODI (3)	Range, 8-38; median, 12; IQR, 30[a]
Extension	Extension ROM (peak)				
	Lumbar[6,19,23,47]	Range, 25-456; median, 89; IQR, 109.25[a]	Inclinometer (4)	Pain: VAS (2) Activity limitation: ODI (1), PSFS (1), QBPDS (1), LBP Disability Index (1)	Range, 3-11; median, 5.5; IQR, 5.75[a]
Lateral flexion	Lateral flexion ROM (peak)				
	Lumbar[12,47]	Range, 56-456; median, 256; IQR, 400[a]	Inclinometer (1), electromechanical (1)	Pain: MPQ (1) Activity limitation: LBP Disability index (1)	Range, 2-3; median, 2.5; IQR, 1[a]
	Multisegment[2,23,66]	Range, 88-98; median, 96; IQR, 10[a]	Fingertip to floor (3)	Pain: NRS (1) Activity limitation: RMDQ (2), ODI (1)	Range, 3-3.5; median, 3.5; IQR, 0.5[a]
Rotation	Rotation ROM (peak)				
	Lumbar[12,23]	Range, 56-88; median, 72; IQR, 32[a]	Electromechanical (1), goniometer (1)	Pain: modified MPQ (1) Activity limitation: ODI (1)	Range, 2-3; median, 2.5; IQR, 1[a]
	Multisegment[47]	456 participants	Compass	Did not measure pain Activity limitation: LBP Disability Index	3
Summative	Summative ROM (peaks)				
	Lumbar[12,38,42,47,49]	Range, 36-456; median, 132; IQR, 143[a]	Electromechanical (3), inclinometer (1), vector stereograph (1)	Pain: NRS (2), modified MPQ (1) Activity limitation: RMDQ (2), LBP Disability Index (1), 12-item functional impairment VAS (1)	Range, 2-12; median, 4; IQR, 9[a]
	Multisegment[24,45,46]	Range, 27-476; median, 194; IQR, 449[a]	Schober test/fingertip to floor/compass (2), inclinometer (1)	Pain: 5-point NRS (current and average over 1 wk) (1) Activity limitation: FCI (1), LBP Disability Index (1), 12-item functional impairment scale (1)	Range, 20-72; median, 52; IQR, 52[a]
Other	Phase-plot area for spinal kinematics during lifting				
	Multisegment[35,49]	Range, 112-199; median, 155.5; IQR, 87[a]	Electromechanical (2)	Pain: NRS (1) Activity limitation: ODI (1), RMDQ (1)	Range, 12-29.3; median, 20.7; IQR, 17.3[a]

Abbreviations: FCI, Functional Capacity Index; HFQ, Hannover Functional Questionnaire; IQR, interquartile range; LBP, low back pain; MPQ, McGill Pain Questionnaire; NPRS, numeric pain-rating scale; NRS, numeric rating scale; ODI, Oswestry Disability Index; PSFS, Patient-Specific Functional Scale; QBPDS, Quebec Back Pain Disability Scale; RMDQ, Roland-Morris Disability Questionnaire; ROM, range of motion; sEMG, surface electromyography; VAS, visual analog scale.

[a]*The IQR was calculated as the third quartile minus the first quartile.*

Figure 3-1 PRISMA flow diagram. Systematic Review: Cohort studies and RCTs

The 27 included studies investigated the relationship between movement and pain or movement and activity limitation at the individual level 65 times (pain, 26 times; activity limitation, 39 times) (**TABLE 2**). Movements related to flexion (ROM, velocity, electromyography, and lumbopelvic rhythm) accounted for 57% (37/65) of all movements measured. The majority (23/37, 62%) of the flexion parameters were related to flexion ROM. Parameters related to extension were measured 8% (5/65) of the time, lateral flexion 9% (6/65) of the time, rotation 5% (3/65) of the time, summative ROM in the cardinal planes 17% (11/65) of the time, and other measures (such as phase-plot area or lifting spinal position) 5% (3/65) of the time. No studies reporting the lumbar contribution to flexion or timing of lumbar kinematics were identified.

Quality Assessment Within Studies

The risk-of-bias scores at individual study and domain levels are presented in **TABLE 3**, along with their categorization (low, medium, or high risk of bias). All 27 included studies adequately described the participant demographic and clinical characteristics, 24 (89%) adequately described the selection criteria, 19 (70%) had acceptable missingness of data, all reported measuring movements in standardized and valid ways, 26 (96%) reported using reliable measures of movement, 25 (93%) reported using standardized, valid, and reliable pain or activity limitation questionnaires, all (100%) used appropriate statistical analysis, and 3 (11%) reported using an assessor blind to movement, pain, or activity limitation outcome.

We categorized 25 of the 27 studies (93%) as having a high risk of bias, mostly because of uncertainty about assessor blinding, which was only reported in 3 studies (it is possible that some studies blinded assessors but did not report it). Authorities (such as the Cochrane Collaboration[65]) advise that when the outcome assessor is not blinded and an outcome (in this case, movement assessment) could have been influenced by knowledge of the intervention received (analogous here to knowledge of change in pain or activity limitation), review authors should assess whether it is likely that such influence occurred. In our judgment, there was a high risk that lack of blinding would affect the measurement of movement.

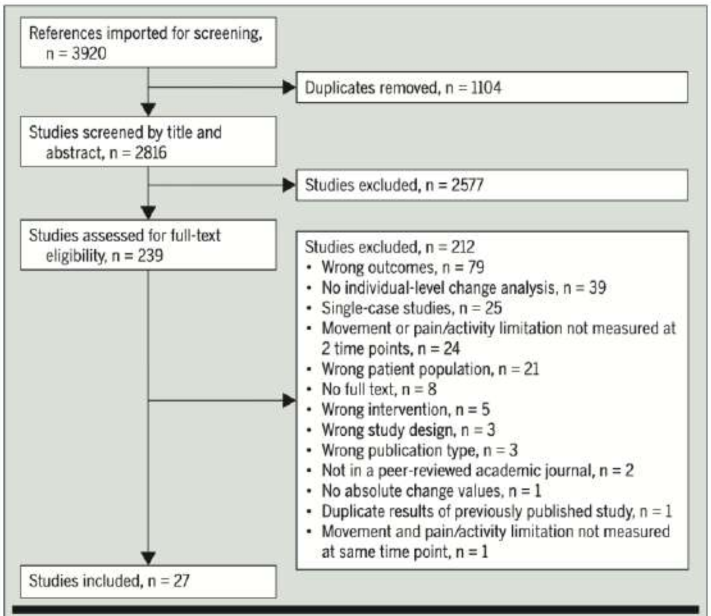

FIGURE 1. PRISMA flow diagram of included studies.

Quality Assessment Across Studies

Starting with a GRADE score of "medium quality" for cohort-derived data,[5,18,63] after consideration of all GRADE criteria, we downgraded the classification to low-quality evidence, defined by GRADE[5] as, "Our confidence in the effect estimate is limited: the true effect may be substantially different from the estimate of the effect." A full description of our GRADE assessment across all domains is detailed in **APPENDIX C**.

Synthesis of Results

The summary results about the relationship between changes in movement parameters, pain, and activity limitation, and the direction of this relationship when present, are displayed in **TABLE 2**.

Movement and Pain A relationship between a change in movement and a change in pain was investigated 26 times in 16 studies[2,6,10,12,19,24,38,40,42,49,54,59,61,62,69,73] (some studies investigated multiple movements), with a relationship found 22% (5.6/26) of the time. In studies that found a relationship,[2,12,40,49,61] increased movement range, velocity, or flexion relaxation was associated with improved pain 100% (5.6/5.6) of the time. The most common measures of pain were the numeric pain-rating scale and the 100-mm visual analog scale (both used 6 times), with other measures of pain (eg, the McGill Pain Questionnaire) used 3 times.

Movement and Activity Limitation A relationship between a change in movement and a change in activity limitation was investigated 39 times in 23 studies[2,9,11,19,23,24,35,38-42,45-47,49,54,59,60,62,66,69,73] (some studies investigated multiple movements), with a relation-

3.5 Discussion

Table 3.2 Summary of relationships. Systematic review: Cohort studies and RCTs

ship found 37% (14.4/39) of the time. In the studies that found a relationship,[9,11,23,38,40,41,45-47,49,54,60,62,66] increased movement range, velocity, or flexion relaxation was associated with improved activity limitation 90% (12.9/14.4) of the time. The most common measure of activity limitation was the Roland-Morris Disability Questionnaire (used 10 times), followed by the Oswestry Disability Index (used 5 times), with other measures (such as the Quebec Back Pain Disability Scale, the Functional Capacity Index, and the Hannover Functional Questionnaire) used 7 times.

Movement, Outcome, and Direction When considering investigations of pain and activity limitation together, a relationship between movement and outcome was observed 31% (20.0/65.0) of the time. Increased range, velocity, or flexion relaxation was associated with improved clinical outcome 93% (18.5/20.0) of the time.

Sensitivity Analysis

As 25 of 27 (93%) studies were categorized as having a high risk of bias, there were insufficient data to perform a sensitivity analysis of the prevalence of a relationship in only the studies with a low risk of bias.

Baseline values of pain and activity limitation in the included studies were comparable to the values reported in NSLBP RCTs,[21,25,68] above reported levels for "disabling back pain,"[71] and similar between the studies that did and did not identify a relationship. The detailed results of these additional analyses can be found in **APPENDIX E**.

Two video abstracts of this systematic review are also available (see https://youtu.be/iUgVOdtQPi8 for the full video abstract and https://youtu.be/yFesgTl-ZynM for the brief video abstract).

DISCUSSION

THERE WAS A RELATIONSHIP between changes in volitional spinal movement (including muscle activity) and changes in pain or activity limitation 31% of the time (20 of the 65 associations tested) in 27 low-quality studies involving 2739 participants. The relationship was between increased

TABLE 2 SUMMARY OF RESULTS ABOUT A RELATIONSHIP BETWEEN CHANGE IN MOVEMENT AND CHANGE IN PAIN OR ACTIVITY LIMITATION

		Movement and Pain		Movement and Activity Limitation	
Movement Category	Movement Parameter/ Measurement Type	Times Investigated, n	Supporting Relationship, n (direction)[a]	Times Investigated, n	Supporting Relationship, n (direction)[a]
Flexion	Flexion ROM				
	Lumbar	Five[6,19,40,59,62]	1 (1↑, 0↓)	Seven[19,23,40,47,59,62,66]	2.5 (1.5↑, 1↓)
	Multisegment	Four[10,40,54,62]	0	Seven[9,11,38,54,60,62,66]	5 (5↑, 0↓)
	EMG (FRR)[b]	Five[59,61,62,69,73]	0.25 (0.25↑, 0↓)	Four[41,59,62,73]	1 (1↑, 0↓)
	Velocity and rhythm	Two[54,62]	0	Three[54,60,62]	0.1 (0.1↑, 0↓)
Extension	Extension range				
	Lumbar	Two[6,19]	0	Three[19,23,47]	0
Lateral flexion	Lateral flexion ROM				
	Lumbar	One[12]	1 (1↑, 0↓)	One[47]	1 (1↑, 0↓)
	Multisegment	One[2]	1 (1↑, 0↓)	Three[2,23,66]	1.5 (1.5↑, 0↓)
Rotation	Rotation ROM				
	Lumbar	One[12]	1 (1↑, 0↓)	One[23]	1 (1↑, 0↓)
	Multisegment	...	...	One[47]	1 (1↑, 0↓)
Summative	Summative ROM				
	Lumbar	Three[12,42,49]	1.3 (1.3↑, 0↓)	Four[39,42,47,49]	0.3 (0.3↑, 0↓)
	Multisegment	One[24]	0	Three[24,45,46]	1 (0.5↑, 0.5↓)
Other	Other[c]				
	Lumbar	One[49]	0	Two[35,49]	0

Abbreviations: EMG, electromyography; FRR, flexion-relaxation ratio; ROM, range of motion.
[a]*Vote-counting system (scored 1.0 per parameter). For studies that used multiple measures for a single movement parameter, the value of 1 was divided by the total number of measures used. For example, if a study only used an inclinometer to measure flexion ROM, and that parameter showed a relationship, then the vote from that study was 1.0. However, if that study also utilized 3 other methods of flexion ROM measurement, and only the inclinometer measurement showed a relationship, then the vote from that study would be 0.25. The ↑ symbol means that an increase in that parameter was related to an improvement in pain or activity limitation, and the ↓ symbol means that a decrease in that parameter was related to an improvement in pain or activity limitation.*
[b]*A higher value indicates greater relaxation (less muscle activity) during peak flexion.*
[c]*Included phase-plot area and spinal kinematics during lifting.*

Table 3.3 Risk of Bias assessment. Systematic review: Cohort studies and RCTs

range, velocity, or flexion relaxation and improved pain and activity limitation 93% of the time (18.5 of 20 relationships observed) (**FIGURE 2**). Baseline pain and activity limitation did not appear to explain the presence of a relationship.

Quality of the Evidence

The low overall quality of evidence (by GRADE assessment criteria) was influenced predominantly by 2 domains: domain 1 (risk of bias) and domain 4 (indirectness). A lack of reporting on assessor blinding influenced the risk of bias domain, and designs and interventions that could not accommodate the heterogeneous movements in people with NSLBP[37] influenced the indirectness domain.

Interpretation of Findings

The infrequency of a relationship may be evidence that, in most people with NSLBP, changes in pain or activity limitation are unrelated to changes in movement. Alternatively, it could be evidence that some people with NSLBP move normally and not all of them have a movement problem that is amenable to change. A recent cohort study of 266 people found that a subgroup (25%) of people with NSLBP move normally, despite their pain and activity limitation.[30] Further, our findings could be evidence

TABLE 3 RISK-OF-BIAS ASSESSMENT[a]

	Item[b]									
Study	1	2	3	4[c]	5[c]	6[c]	7[c]	8[c]	9[c]	Overall Risk[d]
Anderson et al[2]	1	1	1	1	1	1	1	1	U	High
Beladev and Masharawi[8]	1	1	1	1	1	1	1	1	U	High
Caporaso et al[9]	1	1	1	1	1	1	1	1	U	High
Demoulin et al[10]	1	1	0	1	1	1	1	1	U	High
Ekedahl et al[11]	1	1	0	1	1	1	1	1	U	High
Elnaggar et al[12]	1	0	1	1	1	1	1	1	U	High
Helmhout et al[19]	1	1	0	1	1	1	1	1	U	High
Hurri et al[23]	1	1	U	1	1	1	1	1	U	High
Johannsen et al[24]	1	1	0	1	1	1	1	1	0	High
Loisel et al[28]	1	1	1	1	U	1	1	1	1	High
Mannion et al[40]	1	1	1	1	1	1	1	1	U	High
Mannion et al[39]	1	1	1	1	1	1	1	1	U	High
Mannion et al[38]	1	1	1	1	1	1	1	1	1	Low
Marshall and Murphy[41]	1	1	1	1	1	1	1	1	U	High
Martin et al[42]	1	1	0	1	1	U	U	1	U	High
Mellin et al[47]	1	1	1	1	1	1	1	1	U	High
Mellin et al[45]	1	1	1	1	1	1	1	1	U	High
Mellin et al[46]	1	0	0	1	1	U	U	1	U	High
Mieritz et al[49]	1	1	0	1	1	1	1	1	U	High
Nordstoga et al[54]	1	1	1	1	1	1	1	1	U	High
Pagé et al[59]	1	1	1	1	1	1	1	1	U	High
Poitras et al[60]	1	1	1	1	1	1	1	1	1	Low
Qiao et al[61]	1	1	1	1	1	1	1	1	U	High
Shahvarpour et al[62]	1	1	1	1	1	1	1	1	U	High
Strand et al[66]	1	0	1	1	1	1	1	1	U	High
Watson et al[69]	1	1	1	1	1	1	1	1	U	High
Xia et al[73]	1	1	1	1	1	1	1	1	U	High
Domain-level prevalence	100%	89%	70%	100%	96%	93%	93%	100%	11%	...

Abbreviation: U, unclear.
[a]*Modified from Moola et al.[51] Scoring: 1, adequate; 0, not adequate.*
[b]*Items: 1, Demographics; 2, Selection criteria; 3, Missingness; 4, Movement standard/valid; 5, Movement reliable; 6, Pain/activity limitation standard/valid; 7, Pain/activity limitation reliable; 8, Appropriate analysis; 9, Assessor blinding.*
[c]*Critical risk of bias.*
[d]*High risk, any of the critical risks were scored negatively or were unclear; medium risk, all of the critical risks were scored positively, but some noncritical risks were scored negatively or were unclear; low risk, scored positively on all items.*

Figure 3-2 Relationships observed. Systematic review: Cohort studies and RCTs

that an unmeasured factor was the main catalyst for change, and this factor may differ among individuals.

In previous research, improvements in psychological factors (eg, distress, pain catastrophizing, or fear avoidance) were more strongly related to improved pain or activity limitation than to movement.[38,39,54] Positive experiences and reduced sense of threat following the targeting and safe completion of movements perceived as dangerous or damaging may improve pain and activity limitation, irrespective of change in the targeted movements. Therefore, some therapeutic effects observed with interventions targeting movement may not be related to change in that movement, but simply to changes in the perceived threat value of movement.

Factors That May Influence the Relationship Between Change in Movement and Change in Pain or Activity Limitation

While it is possible that no relationship between changes in movement and changes in pain or activity limitation may exist at the individual level, several scenarios could preclude the identification of such a relationship. Due to the heterogeneity of NSLBP,[37,56] the same factors may not contribute to participants' experience of pain and activity limitation. Specifically, some participants may not have an impairment of the movement measured. Not measuring individually relevant movement parameters is a potential limitation among cohort studies that rely on consistent parameters measured across all participants. For example, if flexion is the measured movement parameter among a cohort of people with NSLBP and some did not have flexion limitations but reported limitations in extension, only analyzing relationships between changes in flexion and changes in pain or activity limitation would underestimate the true relationship between changes in movement and changes in pain or activity limitation. The lack of a frequent relationship in our systematic review of cohort studies may indicate that related movement parameters are person specific.

Frequently, a movement parameter measured and compared to changes in pain or activity limitation will not be the one directly targeted by the intervention. When the measured movement and aims of the intervention are not well aligned, the prevalence of relationships between changes in movement and changes in pain may be underestimated. For example, where studies[6,9,11,24,38-40,49,62] have measured maximum flexion ROM or flexion relaxation as an outcome and found a relationship between its increase and an improvement in the condition, the intervention encouraged movement restriction or stabilization of the spine, neutral positions, and bracing of the trunk muscles, which might have limited changes in the measured movement parameter, precluding the identification of a relationship. Additionally, for example, heterogeneity across the duration of participants' back pain (acute through persistent) and their backgrounds (age, occupation, working versus not working, athletes versus nonathletes) might have influenced the identification of a relationship.

There was substantial heterogeneity in the measurement of movement, pain and activity limitation, and the analysis of change in the included studies. The selection of the measured movement parameter (whether it was salient for the participants), the validity and reliability of the tool used to measure movement, as well as the type, reliability, and validity of the pain or activity limitation measure might have influenced our results. However, the risk of bias assessment judged the validity and reliability of the movement, pain, and activity limitation measures to be acceptable, and therefore this is unlikely to have influenced our findings.

Finally, there was considerable variability in the time interval between measures. Some studies measured changes within a week,[61] while others measured changes over a 1.5-year period.[45]

Changes in Movement When a Relationship Was Found

When a relationship was identified, the results regarding the direction of movement changes that were related to improved pain or activity limitation were very consistent. Improved pain or activity

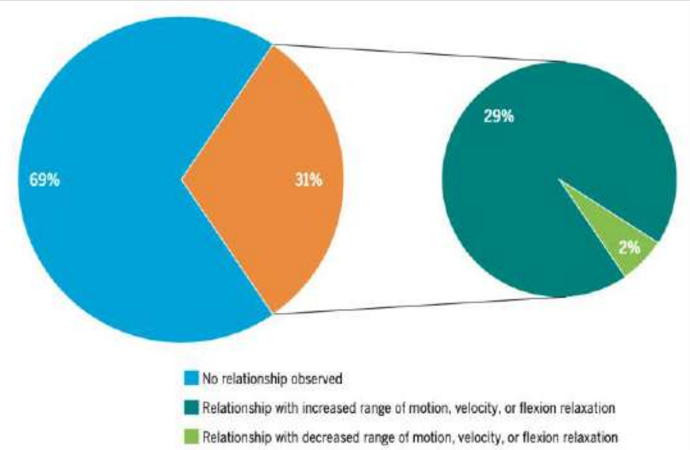

FIGURE 2. Changes in volitional spinal movement and changes in pain or activity limitation were found to have a relationship 31% of the time. Of the 31% observed relationships, 93% involved increased range, velocity, or flexion relaxation.

limitation was consistently associated with increased spinal movement range, velocity, or flexion relaxation of the back extensor muscles. Improvement may represent a return toward normal movement, as there is considerable evidence that people without LBP move, on average, with greater range, velocity, and flexion relaxation than people with LBP.[29-31] When changes in movement are related to improved pain or activity limitation, it is predominantly in recovery from a protective movement behavior. However, the causal direction remains unknown (whether reducing protective movement improves pain and activity limitation or improving pain and activity limitation reduces protective movement).

Psychological factors, such as fear of movement and self-efficacy, have been associated with a protective pattern of movement,[27,43,55,58] as well as pain and activity limitation outcomes.[1,38,39,54] It is plausible that reducing protective movement improves pain or activity limitation, a change potentially mediated by a reduction in pronociceptive protective behaviors (muscle guarding and movement restriction)[57] or improvements in psychological factors, such as fear of movement and self-efficacy.[8,33] Conversely, improvements in pain or activity limitation due to phenomena such as natural history, placebo, nonspecific effects, or changes in other biopsychosocial factors[4,48,72] may result in reducing protective movement.

To our knowledge, this is the first published study that has investigated the relationship between changes across comprehensive volitional movement parameters and changes in pain and activity limitation at the individual level. The only other systematic review with individual-level analysis on this topic only considered spinal ROM parameters as measures of volitional spinal movement.[64] We also considered velocity, spinal muscle activity, extension ROM, ROM during functional tasks, lumbar contribution to flexion, and the timing of lumbar kinematics. We found a prevalence of 31% (20 of 65 associations), similar to the previous review's finding of 34% (6.5/19 associations),[64] despite including broader movement parameters, which increases our confidence in the results. The results of our systematic review are also comparable to those of a previous systematic review[32] in which associations between changes in movement and improvement in pain or activity limitation were infrequently observed at the group level.

Strengths

The broad selection criteria were a strength of this systematic review. Including numerous study designs, all physical interventions, all durations of NSLBP, various volitional movement measures, and all studies since database inception; searching multiple electronic databases; and using a comprehensive search strategy developed in collaboration with a faculty librarian mean that it is likely that we captured the pertinent studies.

Limitations

Potential limitations are language bias (due to only including English-language publications), publication bias (due to only including peer-reviewed studies), selective reporting by the authors of included studies (due to a lack of registered study protocols), exclusion of studies that used surgical or pharmacological interventions, and the use of a conventional ($P<.05$) but arbitrary threshold of statistical significance when identifying the presence of a relationship. Additionally, due to the heterogeneity of the included studies, vote counting was the most appropriate method to synthesize the results.

Considerations

Changes From PROSPERO Registration Following inspection of the size of the initial search yield, we restricted the scope of the systematic review to (1) include only movements and exclude static postures, (2) exclude surgical or pharmacological interventions, and (3) exclude low-quality single-case studies. The PROSPERO registration was therefore reworded to reflect those changes.

Clinical Implications

Infrequent identification of a relationship between changes in movement and pain suggests that movement does not necessarily have to change for pain or activity limitation to improve in people with NSLBP. However, a lack of high-quality evidence limits our confidence in this implication. The movement parameters that were consistently associated with improved pain or activity limitation (increased spinal range, velocity, and flexion relaxation) can be observed, targeted, and monitored by clinicians. These movement parameters may have different relevance for different people and may be influenced by various biopsychosocial factors such as levels of fear and self-efficacy,[1,27,43,55,58] which may also require observation, targeting, and monitoring. The lack of a clear relationship lends support to calls for a multidimensional, individualized biopsychosocial approach to managing NSLBP.

Unanswered Questions and Future Research

Much remains unknown about which changes in physical, cognitive, emotional, social, lifestyle, or other factors are important in order to see a subsequent improvement in outcome. High-quality studies that investigate relationships between changes in individually relevant biopsychosocial factors and pain or activity limitation at the individual level would increase our understanding of the factors related to improved outcomes. The quality of future studies could be improved by reporting on assessor blinding, accommodating and assessing movements specific to the limitations of the individual, and using multidimensional interventions that target those individually relevant movements and limitations.

There is little research investigating the relationship between changes in individually relevant movement and changes in pain or activity limitation, or the or-

3.6 Conclusion

der in which these occur. Study designs that accommodate heterogeneity and repeatedly measure numerous multidimensional factors, including individually relevant movement, such as rigorous single-case designs[7,15] as well as mediation analyses of large-cohort and RCT data may help provide insights into causality[20] and mechanisms of improvement among people with NSLBP. Despite the infrequent identification of a relationship in the current literature, the existing evidence base is predominantly of low quality. Thus, high-quality research is required to provide more dependable insights about this topic.

CONCLUSION

A CHANGE IN VOLITIONAL SPINAL movement was infrequently (31%, or 20 of the 65 associations investigated) related to a concomitant change in pain or activity limitation in people with NSLBP. This was observed across multiple movement parameters, measures, study periods, and interventions. When a change in movement was associated with improved pain or activity limitation, it almost always occurred via an increase in spinal range, velocity, or flexion relaxation of the back extensor muscles.

KEY POINTS

FINDINGS: There was low-quality evidence that changes in volitional spinal movement (including muscle activity) were infrequently (31%, or 20/65 associations tested) related to changes in pain or activity limitation at the individual level among people with nonspecific low back pain. Where relationships were observed, improved pain and activity limitation were consistently (93%, or 18.5/20 relationships observed) related to increased spinal movement range, velocity, or flexion relaxation of spinal extensor muscles.

IMPLICATIONS: Infrequent observation of a relationship between changes in these domains suggests that movement does not necessarily need to change for pain or activity limitation to improve. Changes in other biopsychosocial factors may relate more to improvement in low back pain, and these may be different for different people, lending support to calls for a multidimensional and individualized approach to the assessment and management of nonspecific low back pain.

CAUTION: Considerable heterogeneity among studies, numerous methodological limitations, and a paucity of high-quality evidence preclude a definitive understanding of these relationships.

STUDY DETAILS

AUTHOR CONTRIBUTIONS: All authors contributed to the conception, design, analysis, and interpretation of this study. All authors contributed to drafting and critically revising the manuscript and assume responsibility for the work.

DATA SHARING: All data relevant to the manuscript are included in the article or within the appendices.

PATIENT AND PUBLIC INVOLVEMENT: There was no patient or public involvement in this research.

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3.8 Chapter 3 Appendices

3.8.1 Appendix A

Table 3.4 Appendix A. Search strategy. Systematic review: Cohort studies and RCTs

APPENDIX A

SEARCH STRATEGY USED IN THE MEDLINE DATABASE

1. Case Reports/
2. (case report* or case series or case-series or single-case report).ti,ab,pt.
3. 1 or 2
4. Low Back Pain/
5. (Low* back pain or low* back ache or low* backache or lumbar pain or lumbar spin* pain or backache or lumbago or low* back dysfunction or spondylosis or dorsalgia or back strain or back pain or spin* pain or low* back syndrome or lumbopelvic pain or lumbo-pelvic pain or NSLBP or CLBP or NSCLBP or Persistent low* back pain or PLBP).ti,ab.
6. 4 or 5
7. exp Movement/ or exp Biomechanical Phenomena/ or Range of Motion, Articular/
8. (Kinematic* or Movement* or movement pattern* or ROM or Range of motion* or Range of movement* or excursion or movement control or motor control or stabilisation or stability or angle or lordosis angle or hip contribution or lumbar contribution or pelvi* contribution or position or relative position or joint position or dynamic position or dynamic posture or speed or velocity or timing or flexibility or mobility or muscle activ* or magnitude or EMG or sEMG or electromyography or electromyogram or surface electromyogra* or muscle activation patterns).ti,ab.
9. (flexion relaxation or flexion-relaxation).mp.
10. ((flexion relaxation or flexion-relaxation or FR) and (ratio or response or phenomena or phenomenon)).ti,ab.
11. or/7-10
12. 3 and 6 and 11
13. exp animals/ not humans.sh.
14. 12 not 13
15. reliability.ti. or cross-sectional.pt. or cross sectional.pt. or pregnancy.ti,ab.
16. spinal neoplasms/
17. (cauda equin* or cancer or metastasis or metabolic disorder or neuropathy or surg* or fracture*).mp.
18. 15 or 16 or 17
19. 14 not 18
20. limit 19 to English language
21. Case-control studies/ or cohort studies/ or comparative study/ or evaluation studies/ or follow-up studies/ or longitudinal studies/ or prospective studies/ or treatment outcome/ or exp Clinical Study/ or Case Reports/ or observational study/
22. (cohort or compared or comparison or groups or Case-control or case control or follow up or follow-up studies or treatment outcome or case reports or case series or case-series or case-cohort or case cohort).ti,ab,pt.
23. Randomised Controlled Trials/ or randomi?ed controlled trial*.pt,ti. or randomi?ed controlled study.ti. or randomi?ed clinical trial.ti. or randomi?ed clinical study.ti. or conference proceedings.pt,ti,ab.
24. or/21-23
25. Low Back Pain/
26. (Low* back pain or low* back ache or low* backache or lumbar pain or lumbar spin* pain or backache or lumbago or low* back dysfunction or spondylosis or dorsalgia or back strain or back pain or spin* pain or low* back syndrome or lumbopelvic pain or lumbo-pelvic pain or NSLBP or CLBP or NSCLBP or Persistent low* back pain or PLBP).ti,ab.
27. 25 or 26
28. exp Movement/ or exp Biomechanical Phenomena/ or Range of Motion, Articular/
29. (Kinematic* or Movement* or movement pattern* or ROM or Range of motion* or Range of movement* or excursion or movement control or motor control or stabilisation or stability or angle or lordosis angle or hip contribution or lumbar contribution or pelvi* contribution or position or relative position or joint position or dynamic position or dynamic posture or speed or velocity or timing or flexibility or mobility or muscle activ* or magnitude or EMG or sEMG or electromyography or electromyogram or surface electromyogra* or muscle activation patterns).ti,ab.
30. (flexion relaxation or flexion-relaxation).mp.
31. ((flexion relaxation or flexion-relaxation or FR) and (ratio or response or phenomena or phenomenon)).ti,ab.
32. 30 or 31
33. 28 or 29 or 32
34. (correlat* or regression or association or covarian*).ti,ab.
35. ((chang* or improv* or modif* or alter* or increase or decrease or reduction or outcome) adj10 (correlat* or associat* or relat* or contingent)).ti,ab.
36. (explain adj3 varian*).ti,ab.
37. 34 or 35 or 36
38. 24 and 27 and 33 and 37

APPENDIX A

39. exp animals/ not humans.sh.
40. 38 not 39
41. reliability.ti. or cross-sectional.pt. or cross sectional.pt. or pregnancy.ti,ab.
42. spinal neoplasms/
43. (cauda equin* or cancer or metastasis or metabolic disorder or neuropathy or surg* or fracture*).mp.
44. 41 or 42 or 43
45. 40 not 44
46. limit 45 to English language
47. 20 or 46

3.8.2 Appendix B

Table 3.5 Appendix B. Critical appraisal tool. Systematic Review: Cohort studies and RCTs

[LITERATURE REVIEW]

APPENDIX B

ADAPTED JOANNA BRIGGS INSTITUTE CRITICAL APPRAISAL TOOL[51] FOR COHORT STUDIES[a]

Risk-of-Bias Item	Description
1. Were the demographic and clinical characteristics of the participants adequately described?	Description of the participants adequate enough to understand how generalizable (externally valid) the findings might be to other settings
2. Were the selection criteria for participants adequately described?	Knowledge of how the participants were selected is important to also understand how generalizable the findings are (eg, the sample only included participants with certain traits, such as generalized hypermobility)
3. Was there an acceptable missingness of data?	Data missingness is not in excess of 20% (greater than 80% of the data were analyzed). When applicable, statistical analysis that handles missing data well is used (eg, generalized estimating equations, mixed-effect models, latent growth models). Nonrandom missingness from people in a cohort can reduce external validity, while missingness of data time points in longitudinal studies can reduce internal validity
4. Were the movements assessed in a standardized and valid way?	The study clearly describes the method of measurement of movements. Assessing validity requires that a "pseudo-gold standard" is available and to which the measure has been compared, or that construct and concurrent validity have been quantified in some other way. The measurement needs to be well described and referenced unless it is well known
5. Were movements assessed in a reliable way?	In this context, reliability (reproducibility) refers to the quantification of test-retest variability. The measure needs to be well known or, if it is not well known, referenced
6. Were pain and/or activity limitation assessed in a standardized and valid way?	The study should clearly describe the method of measurement of pain and/or activity limitation. Validity requires some demonstration (eg, a reference) of construct and concurrent validity
7. Were pain and/or activity limitation assessed in a reliable way?	Reliability refers here to the quantification of test-retest variability. The method of measurement needs to be well known or, if it is not well known, referenced
8. Was appropriate statistical analysis used?	Transparency and appropriate selection of the analytical strategy used. In this case, appropriate statistical approaches would include forms of correlation, regression, and visual analysis
9. Was the assessment of movement (and its change) blind to the assessment of pain or activity limitation (and its change), or vice versa?	Assessor knowledge of participant self-report of pain or activity limitation (or its change) may have biased the assessor's subsequent assessment of movement (or vice versa). If assessor blinding is reported, a score of 1 ("yes") is given; if nonblinding of assessors is reported, a score of 0 ("no") is given; and if it is not clear whether blinding of assessors took place, a rating of "unclear" is given

[a]*Each item is scored "yes," "no," "unclear," or "not applicable."*

3.8.3 Appendix C

Appendix C. GRADE assessment. Systematic Review: Cohort studies and RCTs

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APPENDIX C

SCORES AND REASONING FOR THE 5 GRADE DOMAINS ASSESSING QUALITY OF EVIDENCE ACROSS STUDIES

The GRADE guidelines suggest starting at "medium quality" for research using cohort designs, and we used the other GRADE criteria to upgrade or downgrade the quality score.

Domain 1: Risk of Bias

Of the individual studies included in this review, 93% were categorized as low quality for our research question, and only 7% as high quality. For many studies, this categorization was due to uncertainty about the blinding of assessors, because this aspect was unreported.

Domain 2: Imprecision

The inclusion of over 2700 individuals with nonspecific low back pain from 27 different studies improves the generalizability and precision of the systematic review. However, the use of movement measurement tools that have uncertain within- and between-session error resulted in a lack of confidence in identifying true change.

Domain 3: Inconsistency

Infrequently identifying a relationship among both pain and activity limitation outcomes, relative consistency among the significant *r* values detailed in **APPENDIX D**, and the very consistent findings regarding the direction of movement change in the presence of a relationship (92.5%) increase our confidence in the findings.

Domain 4: Indirectness

Variable study designs and variable intervention types and durations, as well as multiple different outcome measures (although generalizable to what would be expected in clinical practice), resulted in heterogeneous studies and populations. Given the likelihood that clinically relevant movements vary across this population and the frequent use of study designs and interventions that were not readily able to identify and target person-specific salient movements, we believe that this often resulted in an inability to investigate the relationship directly.

Domain 5: Publication Bias

Selective publication of studies that show a relationship between changes in movement and pain or activity limitation would be likely to overestimate the presence of a relationship. However, we included studies that did not directly target movement, which may minimize the influence of overestimation.

Criteria That Could Influence a Decision to Upgrade the Quality Rating

1. *Large Effect*
   Not applicable to this systematic review.
2. *Dose Response*
   Not applicable to this systematic review.
3. *Accounted for All Plausible Residual Confounding*
   Not applicable to this systematic review.

Summary

Starting with a GRADE rating of "medium quality" for cohort-derived data, after consideration of all GRADE criteria, we downgraded the classification to low-quality evidence, defined by GRADE as "our confidence in the effect estimate is limited: the true effect may be substantially different from the estimate of the effect."

The main reason was because, for our research question about a relationship of change between clinical attributes, our judgment is that the degree of indirectness in the included studies and the possibility of a lack of movement assessor blinding resulted in a meaningful threat to the estimate of how frequently that relationship occurs.

Abbreviation: GRADE, Grading of Recommendations Assessment, Development and Evaluation.

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3.8.4 Appendix E

Table 3.6 Appendix E. Baseline comparison. Systematic review: Cohort studies and RCTs

[LITERATURE REVIEW]

APPENDIX E

BASELINE PAIN AND ACTIVITY LIMITATION LEVELS FOR STUDIES THAT INVESTIGATED RELATIONSHIPS BETWEEN CHANGES IN FLEXION-RELATED MOVEMENT PARAMETERS AND CHANGES IN PAIN OR ACTIVITY LIMITATION AT THE INDIVIDUAL LEVEL

Data Source	Design/Outcome Variable	Relationship	No Relationship
Baseline values for studies included in this systematic review	Pain (0-100)[a]	54 (54-54)	49 (21-74)
	Studies, n	1	8
	IQR[b]	0	7
	Participants per study[a]	148	33 (17-68)
	Activity limitation (0-100)[a]	32 (24-37)	30 (13-49)
	Studies, n	10	6
	IQR[b]	8	11
	Participants per study[a]	54.5 (18-148)	78 (21-111)
Baseline values for trials in individuals with NSLBP[c]	Baseline pain (0-100)	48 ± 14 (51)	
	Baseline activity limitation (0-100)	41 ± 12 (46)	

Abbreviations: IQR, interquartile range; NSLBP, nonspecific low back pain.
[a]*Values are median or median (range).*
[b]*The IQR was calculated as the upper quartile minus the lower quartile.*
[c]*Values are mean ± SD (median). The following studies were used for comparison:*

Brinkhaus B, Witt CM, Jena S, et al. Acupuncture in patients with chronic low back pain: a randomized controlled trial. Arch Intern Med. *2006;166:450-457. https://doi.org/10.1001/archinte.166.4.450*
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Frost H, Moffett JAK, Moser JS, Fairbank JC. Randomised controlled trial for evaluation of fitness programme for patients with chronic low back pain. BMJ. *1995;310:151-154. https://doi.org/10.1136/bmj.310.6973.151*
Hill JC, Whitehurst DG, Lewis M, et al. Comparison of stratified primary care management for low back pain with current best practice (STarT Back): a randomised controlled trial. Lancet. *2011;378:1560-1571. https://doi.org/10.1016/S0140-6736(11)60937-9*
Kamper SJ, Apeldoorn AT, Chiarotto A, et al. Multidisciplinary biopsychosocial rehabilitation for chronic low back pain. Cochrane Database Syst Rev. *2014:CD000963. https://doi.org/10.1002/14651858.CD000963.pub3*
Moffett JK, Torgerson D, Bell-Syer S, et al. Randomised controlled trial of exercise for low back pain: clinical outcomes, costs, and preferences. BMJ. *1999;319:279-283. https://doi.org/10.1136/bmj.319.7205.279*
UK BEAM Trial Team. United Kingdom back pain exercise and manipulation (UK BEAM) randomised trial: effectiveness of physical treatments for back pain in primary care. BMJ. *2004;329:1377. https://doi.org/10.1136/bmj.38282.669225.AE*
Vibe Fersum K, O'Sullivan P, Skouen JS, Smith A, Kvåle A. Efficacy of classification-based cognitive functional therapy in patients with non-specific chronic low back pain: a randomized controlled trial. Eur J Pain. *2013;17:916-928. https://doi.org/10.1002/j.1532-2149.2012.00252.x*

3.8.5 Appendix D

Table 3.7 Appendix D. Results from individual studies. Systematic review: Cohort studies and RCTs

[LITERATURE REVIEW]

APPENDIX D

RESULTS FROM INDIVIDUAL STUDIES

		Movement Reported for Cohort Studies*		Pain Reported for Cohort Studies*			Activity Limitation Reported for Cohort Studies*		
Study, n, Measurement Type, Measurement Tool	Length of LBP, Time Between Measures	Pre	Post	Pre	Post	Related?	Pre	Post	Related?
				Flexion ROM (peak)					
Beladev and Masharawi[6] n = 25 Lumbar Dual inclinometer	>12 wk 8 wk	22.45° ± 8.27° (range, 7.15°-35.8°)	28.55° ± 5.20° (range, 19°-35.30°)	VAS: 7.38 ± 1.62 (range, 5-10)	VAS: 3.17 ± 2.06 (range, 0-7)	No: "change in VAS score was not correlated with changes in lumbar flexion"	...	...	...
Helmhout et al[19] n = 90 Lumbar Spinal mouse inclinometer	>2 y 11 wk	NA	NA	NA	NA	No: "improvements in outcome did not relate to improvement in lumbar mobility"	NA	NA	No: "improvements in outcome did not relate to improvements in lumbar mobility"
Pagé et al[69] n = 21 Lumbar Motion-tracking system	88.36 ± 65.36 mo (range, 12-240 mo) 4-6 wk	NA	NA	NA	NA	No (r = 0.04, P = .703) for a VAS with flexion ROM	NA	NA	No: changes in flexion did not contribute significantly to the models that explained change in disability QBPDS: r = 0.02, P = .830 PSFS: r = 0.11, P = .318
Shahvarpour et al[82] n = 33 Both (lumbar, pelvic, and thoracic ROM) Motion sensors	>4 wk 8 wk	NA	NA	NA	NA	No Lumbar: r = −0.04, P = .826 Thoracic: r = 0.01, P = .954 Pelvis: r NA, $P \geq 1$	NA	NA	1/3 showed a relationship Lumbar: r = 0.42, P = .015 Thoracic: r = 0.19, P = .297 Pelvis: r NA, $P \geq 1$
Caporaso et al[9] n = 32 Multisegment Fingertip to floor	8.6 ± 11.1 y 9 wk	NA	NA	...	...	...	NA	NA	Yes RMDQ: r = 0.63, P<.001
Ekedahl et al[11] n = 65 Multisegment Fingertip to floor	>12 wk 4 wk	24 ± 16 cm	Change: 12 ± 3 cm	...	...	...	RMDQ: 11.2 ± 5.6	Change: 5.2 ± 5.4	Yes RMDQ: r = 0.66, P<.001
Hurri et al[23] n = 88 Lumbar 2-goniometer method	9.7 ± 7.3 y 3 wk	43° ± 10°	48° ± 10°	...	...	...	RMDQ: 29 ± 15	RMDQ: 20 ± 16	No (r = −0.02, NS)

Table continues on page A2.

APPENDIX D

Study, n, Measurement Type, Measurement Tool	Length of LBP, Time Between Measures	Movement Reported for Cohort Studies[a]		Pain Reported for Cohort Studies[a]			Activity Limitation Reported for Cohort Studies[a]		
		Pre	Post	Pre	Post	Related?	Pre	Post	Related?
Mannion et al[40] n = 148 Lumbar Electromechanical device	... 3 mo	NA	NA	NA	NA	Yes ($r = 0.30$, $P = .0006$)	NA	NA	Yes ($r = 0.18$, $P = .04$)
Mellin et al[47] n = 456 Lumbar Dual inclinometer	NA 3 wk	NA	NA	...	...	...	NA	NA	No Male, $r = 0.05$, NS; female, $r = 0.07$, NS
Strand et al[66] n = 98 Both Kyphometer and fingertip to floor	"Long lasting" 3-5 wk	Spondylometry: 96.6° ± 18.7° Fingertip to floor: 13.8 ± 15.5 cm	Spondylometry: 103.1° ± 17.8° Fingertip to floor: 8.4 ± 13.4 cm	...	...	...	HFQ: 10.2 ± 4.4 RMDQ: 11.8 ± 4.4	HFQ: 7.9 ± 5.3 RMDQ: 8.9 ± 5.5	3/4 showed a relationship HFQ and spondylometry: $r = 0.27$, $P<.05$ HFQ and fingertip to floor: $r = 0.44$, $P<.01$ RMDQ and fingertip to floor: $r = 0.22$, $P<.05$ RMDQ and spondylometry: $r = 0.08$, $P>.05$
Mannion et al[38] n = 32 Multisegment Fingertip to floor	>3 mo 9 wk	NA	NA	VAS: 46 (estimated from graph)	VAS: 36 (estimated from graph)	NA	RMDQ: 9.12 (estimated from graph)	RMDQ: 6.48 (estimated from graph)	Yes ($r = 0.45$, $P = .009$)
Nordstoga et al[54] n = 44 Multisegment Motion sensor	Any length (62% had pain for >9 mo) 3 mo	ROM: 119° ± 25.1° Peak flexion velocity: start, 61.0°/s ± 22.6°/s; middle, 62.8°/s ± 25.4°/s; end, 47.2°/s ± 22.6°/s	Change in ROM: 10.3° (95% CI: 1.4°, 19.2°) Peak flexion velocity: start, 18.7°/s (95% CI: 10.4°/s, 27.1°/s); middle, 17.9°/s (95% CI: 9.4°/s, 26.4°/s); end, 16.1°/s (95% CI: 7.8°/s, 24.5°/s)	VAS: 5.4 ± 2.2	VAS: 2.9 ± 2.1	No: changes in ROM or peak velocity were not associated with changes in pain	ODI: 23.6 ± 12.4	ODI: 14.4 ± 12.1	Yes: 1° increase in ROM was weakly associated with less activity limitation (−0.14 points; 95% CI: −0.22, 0.06) Changes in peak velocity were not associated with changes in activity limitation
Poitras et al[60] n = 111 Multisegment Optoelectric system	Subacute 28 wk	NA	NA	...	...	...	ODI: 30.4 ± 15.5	ODI: 15.2 ± 14.3	Reported no relationship; no correlation values given

Table continues on page A3.

APPENDIX D

Study, n, Measurement Type, Measurement Tool	Length of LBP, Time Between Measures	Movement Reported for Cohort Studies[a]		Pain Reported for Cohort Studies[a]			Activity Limitation Reported for Cohort Studies[a]		
		Pre	Post	Pre	Post	Related?	Pre	Post	Related?
Demoulin et al[10] n = 17 Both Rachimetry and modified Schober test	11 ± 9 y 6 wk	Spinal flexion (rachimetry): 40.2 ± 8.4 Schober test: 6.7 ± 1.4	Spinal flexion (rachimetry): 40.8 ± 12.8 Schober test: 7.1 ± 1.4	VAS: 43.6 ± 23	VAS: 18.9 ± 14	No	...	...	...
Flexion EMG									
Marshall and Murphy[41] n = 18 Lumbar sEMG: L4-5 (FRR)	4.8 y 12 wk	3.26 ± 3.43	6.53 ± 3.34	VAS: 47.39 ± 23.72	VAS: 23.94 ± 19.71	Did not assess	ODI: 24% (estimated from graph)	ODI: 10% (estimated from graph)	Yes: "increases in the FRR best explained changes measured by the ODI.... The change in erector spinae FRR explained 38% of the variance in the change in ODI score"
Pagé et al[59] n = 21 Lumbar sEMG: L3 bilaterally (FRR)	88.36 ± 65.36 mo (range, 12-240 mo) 4-6 wk	NA	NA	NA	NA	No significant relationship was found between changes in clinical outcome and neuromechanical variable	NA	NA	No significant relationship was found between changes in clinical outcome and neuromechanical variable
Qiao et al[61] n = 45 Lumbar sEMG: 2 cm lateral to L4	Acute NSLBP 1 wk	Flexion: 68.79 ± 19.56 μV Maintained flexion: 72.38 ± 12.39 μV Extension: 87.82 ± 21.48 μV Upright: 20.98 ± 7.51 μV	Flexion: 60.28 ± 17.26 μV Maintained flexion: 28.79 ± 11.1 μV Extension: 110.65 ± 23.16 μV Upright: 20.10 ± 7.13 μV	VAS: 5.15 ± 1.58	VAS: 2.05 ± 1.03	1/4 reported a significant correlation Flexion: r = 0.187, P = .312 Maintained flexion: r = 0.869, $P \leq .001$ Extension: r = 0.294, P = .114 Upright: NS	...	...	...
Shahvarpour et al[62] n = 33 Lumbar sEMG: longissimus, iliocostalis, and multifidus (FRR)	>4 wk 8 wk	NA	NA	NA	NA	No (r = −0.31, P = .066)	NA	NA	No (r = −0.18, P = .283)

Table continues on page A4.

APPENDIX D

Study, n, Measurement Type, Measurement Tool	Length of LBP, Time Between Measures	Movement Reported for Cohort Studies[a]		Pain Reported for Cohort Studies[a]			Activity Limitation Reported for Cohort Studies[a]		
		Pre	Post	Pre	Post	Related?	Pre	Post	Related?
Watson et al[69] n = 36 Lumbar sEMG: L1-2, L4-5 bilaterally (FRR)	4.6 ± 4.2 y 3 wk	Left L1-2, 2.9 ± 4.5; right L1-2, 2.6 ± 2.9 Left L4-5, 2.3 ± 3.3; right L4-5, 2.6 ± 4.4	Left L1-2, 6.5 ± 10.4; right L1-2, 5.4 ± 7.7 Left L4-5, 4.1 ± 5.8; right L4-5, 3.7 ± 4.8	VAS: 49.6 ± 22.6	NA	No Left L1-2: *r* = −0.10, NS Right L1-2: *r* = −0.12, NS Left L4-5: *r* = −0.15, NS Right L4-5: *r* = −0.15, NS	ODI: 51.1 ± 13.9	NA	NA
Xia et al[73] n = 68 Lumbar sEMG: paraspinals (FRR)	>12 wk (84% had LBP for >1 y) 6 wk	4.7 ± 3.7	5.5 ± 5.6	VAS: 46.1 ± 18.1	VAS: 25.6 ± 25.4	No: "the addition of each physiologic variable did not affect the parameter estimates for LBP intensity over time"	RMDQ: 9.5 ± 4.3	RMDQ: 4.8 ± 4.0	No: "the addition of each physiologic variable did not affect the parameter estimates for LBP-related disability over time"
				Flexion velocity/lumbopelvic rhythm					
Shahvarpour et al[62] n = 33 Lumbar Motion sensors (% lumbar contribution)	>4 wk 8 wk	NA	NA	NA	NA	No (*r* = −0.02, *P* = .908)	NA	NA	Yes (*r* = 0.4, *P* = .019)
Nordstoga et al[54] n = 44 Multisegment Motion sensor (velocity)	Any length (62% had pain for >9 mo) 3 mo	Peak flexion velocity: start, 61.0°/s ± 22.6°/s; middle, 62.8°/s ± 25.4°/s; end, 47.2°/s ± 22.6°/s	Change in peak flexion velocity: start, 18.7°/s (95% CI: 10.4°/s, 27.1°/s); middle, 17.9°/s (95% CI: 9.4°/s, 26.4°/s); end, 16.1°/s (95% CI: 7.8°/s, 24.5°/s)	VAS: 5.4 ± 2.2	VAS: 2.9 ± 2.1	No: changes in ROM or peak velocity were not associated with changes in pain	ODI: 23.6 ± 12.4	ODI: 14.4 ± 12.1	No: changes in peak velocity were not associated with changes in activity limitation

Table continues on page A5.

APPENDIX D

Study, n, Measurement Type, Measurement Tool	Length of LBP, Time Between Measures	Movement Reported for Cohort Studies[a]		Pain Reported for Cohort Studies[a]			Activity Limitation Reported for Cohort Studies[a]		
		Pre	Post	Pre	Post	Related?	Pre	Post	Related?
Poitras et al[60] n = 111 Multisegment Optoelectric system (7 velocity/ rhythm parameters)	Subacute 28 wk	NA	NA	...	...	...	NA	NA	Yes for maximum pelvis velocity (r = 0.51, P = .002) All others were NS and not reported
Shahvarpour et al[62] n = 33 Multisegment Motion sensors (% pelvis contribution)	>4 wk 8 wk	NA	NA	NA	NA	No (r = −0.04, P = .822)	NA	NA	No (r = −0.31, P = .081)
Extension ROM (peak)									
Beladev and Masharawi[6] n = 25 Lumbar Dual inclinometer	>12 wk 8 wk	7.63° ± 4.45° (range, 2.15°-17.15°)	11.14° ± 3.32° (range, 5.3°-20°)	VAS: 7.38 ± 1.62 (range, 5-10)	VAS: 3.17 ± 2.06 (range, 0-7)	No: "change in VAS score was not correlated with changes in lumbar extension"	...	...	...
Helmhout et al[19] n = 90 Lumbar Spinal mouse inclinometer	>2 y 11 wk	NA	NA	NA	NA	No (r = −0.06, P = .624)	NA	NA	No QBPDS: r = −0.02, P = .855 PSC: r = −0.14, P = .211
Hurri et al[23] n = 88 Lumbar 2-goniometer method	9.7 ± 7.3 y 3 wk	17° ± 9°	16° ± 7°	...	...	...	RMDQ: 29 ± 15	RMDQ: 20 ± 16	No (r = 0.02, NS)
Mellin et al[47] n = 456 Lumbar Dual inclinometer	NA 3 wk	NA	NA	...	...	...	NA	NA	No Male: r = −0.02, NS; female: r = 0.10, NS
Lateral flexion ROM (peak)									
Elnaggar et al[12] n = 56 Lumbar Motion-tracking system	>3 mo 2 wk	Flexion exercise group: 98 ± 19.4 Extension exercise group: 97 ± 18.3	Flexion exercise group: 99.4 ± 16.5 Extension exercise group: 98.6 ± 21.1	Flexion exercise group: modified MPQ, 14.1 ± 9.8 Extension exercise group: modified MPQ, 15.9 ± 7.8	Flexion exercise group: modified MPQ, 8.9 ± 9.4 Extension exercise group: modified MPQ, 10.6 ± 8.6	Yes (r = 0.35, P = .008)	...	...	...

Table continues on page A6.

APPENDIX D

Study, n, Measurement Type, Measurement Tool	Length of LBP, Time Between Measures	Movement Reported for Cohort Studies[a]		Pain Reported for Cohort Studies[a]			Activity Limitation Reported for Cohort Studies[a]		
		Pre	Post	Pre	Post	Related?	Pre	Post	Related?
Mellin et al[47] n = 456 Lumbar Dual inclinometer	>2 y 3 wk	NA	NA	...	...	...	NA	NA	Yes Male: r = 0.12, P<.05; female: r = 0.16, P<.05
Anderson et al[2] n = 96 Multisegment Fingertip to floor	>3 mo 3.5 wk	14.0 ± 4.5 cm	Change: 2.8 ± 3.6 cm	NRS: 5.9 ± 1.8	NRS change: 1.2 ± 1.8	Yes (r = 0.272): "weak correlation" reported. No mention of P value	RMDQ: 11.8 ± 4.4	RMDQ change: 2.8 ± 4.2	No (r = 0.194): "no correlation" reported. No mention of P value
Hurri et al[23] n = 88 Multisegment Fingertip distance change	9.7 ± 7.3 y 3 wk	175 ± 38 mm	190 ± 45 mm	...	...	...	RMDQ: 29 ± 15	RMDQ: 20 ± 16	Yes (r = −0.30, P<.01)
Strand et al[66] n = 98 Multisegment Fingertip to floor	"Long lasting" 3-5 wk	Fingertip to floor, 14.0 ± 4.6 cm	Fingertip to floor, 16.8 ± 5.0 cm Change: 2.8 ± 3.7 cm (95% CI: 2.1, 3.5 cm)	...	...	...	HFQ: 10.2 ± 4.4 RMDQ: 11.8 ± 4.4	HFQ: 7.9 ± 5.3 RMDQ: 8.9 ± 5.5	1/2 showed a relationship HFQ: r = 0.22, P<.05 RMDQ: r = 0.18, P>.05
Rotation ROM (peak)									
Elnaggar et al[12] n = 56 Lumbar Motion-tracking system	>3 mo 2 wk	Flexion exercise group: 88.6 ± 18.4 Extension exercise group: 86 ± 18.2	Flexion exercise group: 92.4 ± 18.8 Extension exercise group: 90 ± 20.3	Flexion exercise group: modified MPQ, 14.1 ± 9.8 Extension exercise group: modified MPQ, 15.9 ± 7.8	Flexion exercise group: modified MPQ, 8.9 ± 9.4 Extension exercise group: modified MPQ, 10.6 ± 8.6	Yes (r = 0.35, P = .008)	...	...	...
Hurri et al[23] n = 88 Lumbar 2-goniometer method	9.7 ± 7.3 y 3 wk	45° ± 11°	49° ± 11°	...	...	...	RMDQ: 29 ± 15	RMDQ: 20 ± 16	Yes (r = −0.24, P<.05)
Mellin et al[47] n = 456 Multisegment Compass	>2 y 3 wk	NA	NA	...	...	...	NA	NA	Yes Male: r = 0.12, P<.05; female: r = 0.31, P<.01

Table continues on page A7.

APPENDIX D

Study, n, Measurement Type, Measurement Tool	Length of LBP, Time Between Measures	Movement Reported for Cohort Studies[a]		Pain Reported for Cohort Studies[a]			Activity Limitation Reported for Cohort Studies[a]		
		Pre	Post	Pre	Post	Related?	Pre	Post	Related?
Summative ROM (peak)									
Mieritz et al[49] n = 199 Lumbar Spinal motion analyzer (6-DOF linkage system)	>6 wk (82% for >1 y) 12 wk	NA	NA	NA	NA	2-D circumduction: $r = -0.22$, $P<.01$ 3-D circumduction: $r = -0.09$, $P>.01$ Sagittal ROM: $r = -0.09$, $P>.01$	NA	NA	2-D circumduction: $r = -0.20$, $P<.01$ 3-D circumduction: $r = -0.14$, $P>.01$ Sagittal ROM: $r = -0.15$, $P>.01$
Martin et al[42] n = 36 Lumbar Vector stereograph	>6 wk 4 wk	NA	NA	NA	NA	No: correlations were 0.00 and NS	NA	NA	No: correlations were −0.13 and NS
Elnaggar et al[12] n = 56 Lumbar Motion-tracking system	>3 mo 2 wk	Flexion exercise group: 98.5 ± 23.4 Extension exercise group: 93.9 ± 29.8	Flexion exercise group: 109.5 ± 22.6 Extension exercise group: 95.2 ± 27.6	Flexion exercise group: modified MPQ, 14.1 ± 9.8 Extension exercise group: modified MPQ, 15.9 ± 7.8	Flexion exercise group: modified MPQ, 8.9 ± 9.4 Extension exercise group: modified MPQ, 10.6 ± 8.6	Yes ($r = -0.24$, $P = .007$)	...	...	...
Mannion et al[39] n = 132 Lumbar Spinal motion analyzer (6-DOF linkage system)	Chronic (>3 mo): female, 10.2 ± 9.9 mo; male, 10.2 ± 9.0 mo 3 mo	NA	NA	...	...	...	...	...	No: changes in mobility were not related to changes in disability (univariate) Changes in mobility did not contribute to or account for changes in disability (multivariate)
Mellin et al[47] n = 456 Lumbar Dual inclinometer	NA 3 wk	NA	NA	...	...	...	NA	NA	No Male: $r = 0.00$, NS; female: $r = 0.23$, NS
Johannsen et al[24] n = 27 Multisegment Schober test and sternal elevation	>1 y 5 mo	End group, 5 cm (−3 to 27 was 12.5%); coordination group, 9 cm (−11 to 24 was 12.5%)	NA	Pain score (0-8) (12.5th percentile): endurance treatment group, 6 (5-8); coordination group, 6 (4-8)	NA	No correlation was found between improvements in mobility score and improvements in pain score	Disability (0-12) (12.5th percentile): endurance treatment group, 6 (3-8); coordination group, 5 (2-8)	NA	No correlation was found between improvement in mobility score and improvement in disability score

Table continues on page A8.

APPENDIX D

Study, n, Measurement Type, Measurement Tool	Length of LBP, Time Between Measures	Movement Reported for Cohort Studies[a]		Pain Reported for Cohort Studies[a]			Activity Limitation Reported for Cohort Studies[a]		
		Pre	Post	Pre	Post	Related?	Pre	Post	Related?
Mellin et al[45] n = 476 Multisegment Schober test, finger-tip, compass	>2 y 1.5 y	NA	NA	...	...	...	...	...	Male, no; female, yes Male: $r = 0.06$, $P>.05$ Female: $r = 0.39$, $P<.001$
Mellin et al[46] n = 194 Multisegment Inclinometer and compass	Chronic 12 mo	NA	NA	...	...	...	...	...	Male, no; female, yes Female: B = 0.29, $P<.05$ Male: $P>.1$
Other movement parameters									
Mieritz et al[49] n = 199 Lumbar Spinal motion analyzer (6-DOF linkage system)	>6 wk (82% for >1 y) 12 wk	NA	NA	NA	NA	Phase-plot area: no ($r = -0.12$, $P>.01$)	NA	NA	Phase-plot area: no ($r = -0.13$, $P>.01$)
Loisel et al[35] n = 112 Lumbar Spinoscope and EMG	Subacute, from work incidents, absent from work for >4 wk 12, 24, 52 wk	NA	NA	...	...	...	NA	NA	No correlations between changes in ODI and spino-scope scores

Abbreviations: CI, confidence interval; DOF, degree of freedom; EMG, electromyography; FRR, flexion-relaxation ratio; HFQ, Hannover Functional Questionnaire; LBP, low back pain; MPQ, McGill Pain Questionnaire; NA, not available; NRS, numeric rating scale; NS, not significant; NSLBP, nonspecific low back pain; ODI, Oswestry Disability Index; PSC, Patient Specific Complaints; PSFS, Patient-Specific Functional Scale; QBPDS, Quebec Back Pain Disability Scale; RMDQ, Roland-Morris Disability Questionnaire; ROM, range of motion; sEMG, surface electromyography; VAS, visual analog scale.
[a]*Values are mean or mean ± SD.*

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Corey Parker
Copy Editor
Journal of Orthopaedic & Sports Physical Therapy
1020 N. Fairfax St., Suite 400-A
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Phone: 571-970-1062
coreyparker@jospt.org <mailto:coreyparker@jospt.org>

Chapter 4 Systematic review: Single-case designs

'But I'm an individual' - The relationship between changes in movement and changes in low back pain. A systematic review of single-case designs.

The systematic review in Chapter 3 highlighted that when investigating diverse movement parameters at the individual-level, changes in movement are infrequently related to changes in pain or activity limitation. The identification of an infrequent relationship (31% of the 65 times investigated) is consistent with previous systematic reviews. However, measures of movement, and interventions to potentially address specific changes in movement, were frequently *not* individualised amongst the included studies. That is, the included study designs (cohort studies and RCT) were not readily able to accommodate heterogeneous populations. To address that limitation, we conducted another systematic review of study designs that *are* more readily able to accommodate heterogeneity.

This chapter reports a second systematic review, of single-case designs, that aimed to investigate how frequently *changes* in diverse movement parameters relate to *changes* in low back pain and activity limitation at the individual-level, including the types of change in movement that occur when a relationship is identified. This review has been accepted in *JOSPT Cases*, a case-specific child journal of JOSPT, and will be presented in its accepted format (including formatting requirements for JOSPT Cases). Additional dissemination and knowledge translation materials are presented in Thesis Appendix A.1.2.

The following content has been accepted for publication by *JOSPT Cases*.

Wernli, K., Tan, J., O'Sullivan, P., Smith, A., Campbell, A., & Kent, P.

'*But I'm an individual' - The relationship between changes in movement and changes in low back pain. A systematic review of single-case designs*

4.1 Abstract

Objective: To investigate how often changes in an individual's volitional spinal movement related to changes in their low back pain or activity limitation in studies that accommodated individual heterogeneity.

Design: Aetiology systematic review (PROSPERO CRD42017064436)

Literature Search: Medline, EMBASE, CINAHL and AMED to January 2020.

Study Selection Criteria: Peer-reviewed single-case design (including case-series) articles that reported objectively measured volitional spinal movement and low back pain or activity limitation, before and after non-surgical or non-pharmacological intervention.

Data Synthesis: Summarise the frequency that changes in movement related to changes in pain or activity limitation. In the presence of a relationship, synthesize the type of movement change that related to improved pain or activity limitation.

Results: 23 suitable studies (n = 33 participants) of low overall quality were identified. A relationship between changes in movement and changes in pain or activity limitation was identified 68% of the time (58 out of the 84 times investigated). In the presence of a relationship, improved pain or activity limitation was consistently (97%, or 56 of the 58 relationships) related to increased spinal movement range, velocity, or flexion-relaxation (reduced muscle activity at full flexion).

Conclusion: Amongst study designs that can readily accommodate the heterogeneity of low back pain by individualising the intervention and the assessment of movement, a relationship between changes in movement and changes in pain or activity limitation was frequently observed.

4.2 Introduction

Non-specific low back pain (NSLBP) (Maher et al., 2017) is a common and costly condition (Deloitte, 2019; Frymoyer 1988; Vos et al., 2015) frequently believed to relate to how individuals move their spine (Karayannis et al., 2016). Those with NSLBP typically move their back through less range of motion (ROM), with less velocity, and have increased muscle activity at full flexion (absence of flexion-relaxation (Neblett et al., 2003)) compared to those without NSLBP (Geisser et al., 2005; Laird et al., 2014; Laird et al., 2018). Interventions also frequently target movement under the principal that changing movement relates to improved pain and activity limitation (Karayannis et al., 2016). However, several systematic reviews of randomised controlled trials (RCTs) and cohort studies have demonstrated that changes to movement infrequently relate to changes in pain and activity limitation, irrespective of whether the co-occurrence of changes in group means, or correlations between individual movement and pain or activity limitation change scores were used (Laird et al., 2012; Steiger et al., 2012; Wernli, Tan, et al., 2020). A limitation of the group-level studies summarised in existing reviews, is an inability to assess movements relevant to the individual and provided tailored interventions (Wernli, Tan, et al., 2020). A failure to consider patient heterogeneity in the assessment and treatment of a condition such as NSLBP (Hartvigsen et al., 2018; Lin et al., 2019), may contribute to an incomplete understanding of the relationship between changes in movement and changes in pain or activity limitation (Wernli, Tan, et al., 2020).

Single-case designs are readily able to tailor the movement assessed and intervention used according to individual presentations (Hitchcock et al., 2014; Lillie et al., 2011), positioning them well to explore the relationship from the perspective of the individual (Wernli, Tan, et al., 2020). Systematically reviewing the single-case design literature and reporting on the quality and consistency of the studies, may provide unique and potentially important insights for the heterogenous presentations that clinicians encounter by summarising evidence omitted in previous reviews (Maggin & Odom, 2014; Scruggs & Mastropieri, 2012).

Therefore, our aim was to investigate the individual-level relationship between changes in volitional spinal movement and changes in non-specific low back pain or activity limitation in the available single-case design literature.

4.3 Methods

This prospectively registered systematic review (PROSPERO: CRD42017064436) follows the PRISMA statement for reporting items in systematic reviews (Moher et al., 2009).

4.3.1.1 Information sources and search strategy

In cooperation with a university librarian, we searched relevant electronic databases (Medline, Embase, CINAHL and AMED) from inception to January 8, 2020 using a search strategy adapted from our previous systematic review to only include single-case designs (Wernli, Tan, et al., 2020) (**APPENDIX 1** – see 4.9.1).

4.3.1.2 Selection process and criteria

Following the removal of duplicates, two reviewers independently screened studies using a piloted and standardised form in Covidence (systematic review software, Veritas Health Innovation, Melbourne, Australia. www.covidence.org). Assessment conflicts were resolved by discussion and a third reviewer was consulted if consensus could not be reached.

We included single-case designs (including case-series if they accommodated patient heterogeneity and reported data at an individual-participant level) published in peer-reviewed journals that reported changes in objectively measured volitional spinal movement (defined as intentional, unrestricted lumbar kinematics, including measures of flexion-relaxation or muscle activity related to movement) and changes in pain and activity limitation in people with NSLBP managed non-pharmacologically and non-surgically (additional detail in **APPENDIX 2** – see 4.9.2).

4.3.1.2.1 Quality assessment

An adapted version of the Critical Appraisal Checklist for Case Reports (Moola et al., 2017) from the Joanna Briggs Institute was independently used by two reviewers (with a third reviewer resolving assessment conflicts) to assess the risk of bias within individual studies (adapted tool detailed in **APPENDIX 3** – see 4.9.3).

The Grading of Recommendations Assessment, Development and Evaluation (GRADE) (Guyatt et al., 2008) tool was used to assess the overall quality of evidence across the studies (quality assessment detailed in **APPENDIX 4** – see 4.9.4).

4.3.1.3 Analysis

Two reviewers independently extracted data related to changes in volitional spinal movement and changes in pain or activity limitation. We used vote counting to investigate how frequently a movement parameter showed a relationship. One vote was assigned per study for each movement parameter that showed a relationship. If a study had multiple participants, that vote was multiplied by the proportion of participants who showed a relationship. If a study investigated that movement parameter using multiple measurement methods, that vote was multiplied by the proportion of times investigated that showed a relationship (detailed in Table 4.3 footnote). Movement, pain, and activity limitation changes had to exceed a minimal detectable change (MDC) for the tool used to be considered real change. If no MDC was reported, we searched the literature to identify the most relevant MDC for the tool used (reported in **APPENDIX 5** – see 4.9.5). If a relationship was identified, we also extracted the direction of movement change related to improved pain or activity limitation.

We conducted a comparison of the baseline pain and activity limitation in studies that did and did not identify a relationship to explore if this contributed to explaining whether a relationship was more likely to be found in those with worse pain and more activity limitation. Additionally, where the presence of a relationship was unclear but could be clarified by further analysis (such as through cross-correlation using simulation modelling analysis (Borckardt, 2008)), this was performed (included, where applicable, in **APPENDIX 5** – see 4.9.5).

4.4 Results

We identified 3920 articles and included 23 studies (Acosta-Rua et al., 2008; Callahan, 1993; Caneiro et al., 2013; Dankaerts et al., 2007; Floto, 2004; George et al., 2004; Hwang-Bo & Lee, 2011; Ikeda & McGill, 2012; Johansson & Lindberg, 1995; Jones & Wolf, 1980; Lee, 2017; Leonard et al., 2001; Lopes et al., 2019; Louw et al., 2012; Maluf et al., 2000; Monie et al., 2016; Moore et al., 2015; Ohtsuki, 2014; Robinson, 2016; Stanford, 2002; Takasaki & May, 2018; Wolf et al., 1982; Yoo, 2014) (n = 33 participants) in the final review. The PRISMA flow diagram is presented in FIGURE 2 (see 4.8.1).

4.4.1.1 Quality assessment

The individual study risk of bias scores, domain-level risk of bias, and domain-level inter-rater agreement are presented in Table 4.1 (see 4.7.1). Overall, the studies were rated as high risk of bias, predominantly because of uncertainty about whether assessor blinding occurred. Inter-rater agreement for each risk of bias domain ranged from 91% to 100% (median 96%, IQR 8%).

After consideration of all GRADE domains, we rated the quality of the evidence presented across all studies in this systematic review as low, defined as 'our confidence in the estimate is limited: The true effect may be substantially different from the estimate of the effect' (Guyatt et al., 2008). Despite the strong ability of studies to directly investigate the relationship in question, a lack of assessor blinding, and the likely influence of selective reporting reduced our confidence in the findings (GRADE assessment detailed in **APPENDIX 4** – see 4.9.4).

4.4.1.2 Volitional spinal movements identified

Sample size, measurement tools and the time between measures for each movement are summarised in Table 4.2 (see 4.7.2). Changes in volitional spinal movement and changes in pain or activity limitation were reported 84 times in the 23 studies (Table 4.3 – see 4.7.3). The most common parameter was flexion (49%, or 41/84), followed by extension (19%, or 16/84), lateral flexion (18%, or 15/84) and rotation (8%, or 7/84). Six percent (5/84) were classified as other (for example spinal position during lifting or quadrant range of motion). For the 41 times flexion was measured, 33 (80%) were flexion ROM parameters, 6 (15%) were related to muscle activity, and 2 (5%) were related to velocity.

4.4.1.3 Frequency of a relationship between changes in movement and changes in outcome

Changes in volitional spinal movement were related to changes in pain on 33.5 out of 47 occasions (71%), while this relationship was identified 24 out of 37 (65%) times that changes in movement and changes in activity limitation were reported (Table 4.3 – see 4.7.3). When combining pain and activity limitation findings into a single outcome measure, a relationship between changes in movement and changes in outcome was identified 68% (57.5 out of 84) of the time.

4.4.2 Changes to movement in the presence of a relationship

In the 57.5 occasions that identified a relationship between changes in movement and changes in pain or activity limitation; increased spinal ROM, velocity or flexion-relaxation (reduced muscle activity at full flexion) related to improved pain 98% (32.9 out of 33.5), and improved activity limitation 96% (23.1 out of 24) of the time (Table 4.3 – see 4.7.3). Overall, when combing pain and activity limitation into a single outcome measure, improved outcome (a reduction in pain or activity limitation) was related to increased spinal ROM, velocity, or flexion-relaxation (reduced muscle activity at full flexion) 97% (55.7/57.5) of the time. Data reflecting the magnitude of change for the various tools used among the included studies is presented in **APPENDIX 5** (see 4.9.5).

4.4.3 Additional analyses

Baseline pain and activity limitation comparisons between instances where a relationship was or was not identified did not exceed between-group minimally important differences (Ellard et al., 2017) (**APPENDIX 6** – see 4.9.6).

4.4.4 Dissemination materials and patient public involvement

We produced an infographic (see 4.8.2) and video abstract (**Appendix 7 –** see 4.9.7) to facilitate translation of the study findings. There was no patient or public involvement in this research.

4.5 Discussion

We found low-quality evidence among 23 single-case design studies (n = 33 participants) that identified a relationship between changes in spinal movement or muscle activity and changes in pain or activity limitation 68% of the time (57.5 of 84 occasions). When a relationship was observed, increased movement range, velocity, or flexion-relaxation (reduced muscle activity at full flexion) was related to improved pain and activity limitation 97% of the time (56 of the 57.5 relationships observed).

4.5.1.1 Quality of the evidence

Despite the studies in the current review being able to directly assess the presence of a relationship by individualising the assessment of movement and intervention, a key limitation of studies included in previous reviews (Laird et al., 2012; Steiger et al., 2012; Wernli, Tan, et al., 2020), based on the GRADE assessment (detailed in **APPENDIX 4** – see 4.9.4) the overall quality of evidence was still low. This was predominantly influenced by the risk of bias domain (uncertainty about outcome assessor blinding and the potential effect of sampling bias).

4.5.1.2 Interpretation of findings

The frequent (68% or 57.5 out of 84 times investigated) identification of a relationship in the current systematic review suggests that, in the presence of individualised assessment and treatment, changes in movement frequently relate to changes in pain or activity limitation. However, our confidence in this finding is limited due to the low overall quality of evidence. This finding contrasts with our previous systematic review of cohort studies and RCTs, where a relationship was identified in only 31% (20 out 65) of the times investigated in 27 studies (Wernli, Tan, et al., 2020). Other reviews investigating RCTs and cohort studies also identified an infrequent relationship (Laird et al., 2012; Steiger et al., 2012).

The ability of the studies in the current review to individualise the assessment to the salient patient-reported movement limitations, and target the intervention to these limitations, could explain, at least in part, the difference in the frequency of a relationship in the current review compared to previous reviews (Laird et al., 2012; Steiger et al., 2012; Wernli, Tan, et al., 2020). The current review's inclusion of studies that were more readily able to accommodate the heterogeneity of NSLBP (Maher et al., 2017; Wernli, Tan, et al., 2020) also aligns with current recommendations for best practice from high-quality clinical practice guidelines (Lin et al., 2019), while also aligning with calls for individualised, person-centred approaches to complex conditions such as low back pain (O'Sullivan et al., 2018).

While these findings may indicate that changing individually relevant movement should be a treatment target among people with NSLBP, the findings of this systematic review, in addition to being low-quality, are evidence of association only. Many other biopsychosocial factors such as distress, pain catastrophising or fear avoidance have been shown to be associated with improved pain or activity limitation (Mannion et al., 2012; Mannion et al., 2001; Nordstoga et al., 2019), often showing stronger associations than changes to physical factors.

Further, there was significant heterogeneity in the movement assessment procedures, interventions, and time between measures among the included studies, contributing to a reduced confidence in the findings. Movement assessment varied from finger-tip-to-floor (Callahan, 1993; Louw et al., 2015; Ohtsuki, 2014; Takasaki & May, 2018) to comprehensive laboratory-based 3D kinematic assessment (Dankaerts et al., 2007). Interventions included a single session of verbal and manual cues (Ikeda & McGill, 2012), balance taping (Lee, 2017), 10 sessions of laser and vacuum therapy (Lopes et al., 2019), eight sessions of comprehensive biopsychosocial care (Dankaerts et al., 2007), and many more. While the time between measures varied from immediately (Ikeda & McGill, 2012) to 46 weeks (Johansson & Lindberg, 1995).

4.5.1.3 Changes to movement when a relationship was found

The direction of movement changes related to improved pain or activity limitation when relationships were found was very consistent. Improved pain or activity limitation was associated with increased spinal movement ROM, velocity, or flexion-relaxation of the spinal muscles 97% of the time a relationship was identified, potentially representing a return towards ‘normal movement’. This finding is consistent with our previous systematic review that observed this finding 93% of the time (Wernli, Tan, et al., 2020) and is supported by substantial evidence that people with NSLBP typically move in a more ‘protective’ manner - that is with less ROM, slower and with an inability to relax their spinal muscles at full flexion compared to those without NSLBP (Geisser et al., 2005; Laird et al., 2014; Laird et al., 2018; Laird et al., 2019). However, the causal direction for this relationship remains unknown and other factors such as kinesiophobia and self-efficacy, known to be associated with a protective pattern of movement (Karayannis et al., 2013; Matheve et al., 2019; Olugbade et al., 2019; Osumi et al., 2019), may also play a role.

To our knowledge, this is the first review that has systematically investigated the single-case literature on this topic. The low overall quality of the included studies highlights the need for high-quality research in this area, particularly involving assessor blinding, clear case description (including recruitment source), and replication. A recent replicated case-series in 12 people with disabling NSLBP, where the assessor was blind to the outcome data and a registered protocol was followed (Wernli, O’Sullivan, et al., 2020), provides additional support for the findings of this review. In that study, biomechanical, pain and activity limitation measures were collected up to 20 times over 22 weeks before, during and after a physiotherapy-led intervention, and replicated in 12 people. Strong relationships were observed in 10 out of 12 (83%) participants, and improvements in pain and activity limitation were related to increased spinal movement ROM, velocity, or flexion relaxation 93% of the time (Wernli, O'Sullivan, et al., 2020), findings comparable to our current and previous reviews (Wernli, Tan, et al., 2020). Future research investigating the influence of psychological factors, the perceptions of patients about this relationship, and mediation analyses using larger cohorts would add further understanding about this relationship (Australian and New Zealand Clinical Trials Registry, 2019; Kent et al., 2019).

4.5.1.4 Strengths

The broad selection criteria and comprehensive search strategy means it is likely that we captured the pertinent studies. By only investigating the single-case design literature, this systematic review synthesises evidence often omitted from reviews, whilst that design also better accommodates the heterogeneity of NSLBP, a key limitation of previous reviews (Wernli, Tan, et al., 2020).

4.5.1.5 Limitations

In addition to the limitation that these data were generated from single-case designs, there is potential for the presence of language, publication, sampling, and selective reporting bias. Additionally, we excluded studies that used surgical or pharmacological interventions.

4.5.1.6 Considerations

The initial PROSPERO registration pooled both the cohort and single-case studies into a single systematic review and included postures. However, a considerable search yield led to the decision to report the findings for cohort (including randomised controlled trials) and single-case designs separately as well as omitting the investigation of posture.

4.6 Conclusion

Among the single-case design literature, low-quality evidence identified that changes in movement were frequently (68%, or 57.5 of the 84 times investigated) related to changes in pain or activity limitation in people with NSLBP. When relationships were observed, almost always (97% of the time), improved pain or activity limitation was related to increased spinal movement range, velocity, or flexion-relaxation (reduced muscle activity at full flexion), suggesting a return towards 'less protective' movement as NSLBP improves.

4.6.1.1 Key learning points

Findings

- There was low-quality evidence among the single-case design literature of a frequent (67% of the time) relationship between changes in spinal movement or muscle activity and improved pain or activity limitation.
- In the presence of a relationship, improved pain or activity limitation was consistently (97% of the time) related to increased spinal movement range, velocity, or flexion-relaxation (reduced spinal muscle activity at full flexion).

Implications

- Although the research was of low quality, changes towards ‘less protective’ movement are often associated with improved pain or activity limitation when participant heterogeneity is accommodated during assessment and treatment.
- Evidence is of association only, not of a causal direction. Findings should be interpreted in the context of broad biopsychosocial factors that may also be important for an individual with NSLBP.

Caution

- Considerable heterogeneity, methodological limitations, and the low overall quality of evidence currently limits our confidence in these findings and implications.
- High quality studies are required to test the validity of these findings.

4.7 Tables

4.7.1 Risk of Bias assessment

Table 4.1. Risk of Bias assessment. Systematic review: Single-case designs

Author, year	1. Demographics	2. Movement standard/valid*	3. Movement reliable*	4. Pain/activity limitation standard/valid*	5. Pain/activity limitation reliable*	6. Assessor blinding*	Overall Risk of Bias (low, medium, high)
(Acosta-Rua et al., 2008)	1	1	1	1	1	1	Low
(Callahan, 1993)	1	1	1	1	1	U	High
(Caneiro et al., 2013)	1	1	1	1	1	U	High
(Dankaerts et al., 2007)	1	1	1	1	1	U	High
(Floto, 2004)	1	1	1	1	1	U	High
(George et al., 2004)	1	1	1	1	1	U	High
(Hwang-Bo & Lee, 2011)	1	1	1	1	1	U	High
(Ikeda & McGill, 2012)	0	1	1	1	1	U	High
(Johansson & Lindberg, 1995)	0	1	1	1	1	U	High
(Jones & Wolf, 1980)	1	1	1	1	1	U	High
(Lee, 2017)	1	U	U	1	1	U	High
(Leonard et al., 2001)	1	1	1	1	1	U	High
(Lopes et al., 2019)	1	1	1	1	1	U	High
(Louw et al., 2012)	1	1	1	1	1	U	High
(Maluf et al., 2000)	1	1	1	1	1	U	High
(Monie et al., 2016)	1	1	1	1	1	U	High
(Moore et al., 2015)	1	1	1	1	1	U	High
(Ohtsuki, 2014)	1	1	1	1	1	U	High
(Robinson, 2016)	1	1	1	1	1	U	High
(Stanford, 2002)	1	1	1	1	1	U	High
(Takasaki & May, 2018)	1	1	1	1	1	U	High
(Wolf et al., 1982)	1	1	1	1	1	U	High
(Yoo, 2014)	1	1	1	1	1	U	High
Domain level prevalence	91%	96%	96%	100%	100%	4%	
Domain level inter-rater agreement.	91%	96%	96%	100%	100%	91%	

Abbreviations**:** 1 = Adequate, 0 = Not adequate, U = Unclear, *= critical risk of bias.
High risk = any of the critical risks scored negatively or were unclear, Medium risk = all of the critical risks scored positively but some non-critical risks scored negatively or were unclear, Low risk = scored positively on all items.

4.7.2 Results

Table 4.2. Movement characteristics. Systematic review: Single-case designs

Movement parameter, sample size, measurement tools and time between measures for each movement task.

Movement category (and parameter if applicable)		Sample size (n)	Movement measurement tools (number of studies)	Pain/activity limitation measurement tools (number of studies)	Time between measurements
Flexion	Flexion range of motion (peak) (21 studies. (Acosta-Rua et al., 2008; Callahan, 1993; Caneiro et al., 2013; Dankaerts et al., 2007; George et al., 2004; Hwang-Bo & Lee, 2011; Lee, 2017; Leonard et al., 2001; Lopes et al., 2019; Louw et al., 2012; Maluf et al., 2000; Monie et al., 2016; Moore et al., 2015; Ohtsuki, 2014; Robinson, 2016; Stanford, 2002; Takasaki & May, 2018; Yoo, 2014))	Range: 1 to 9 Median: 1 IQR: 0 (1-1)	Inclinometer or goniometer: 10 Finger-tip-floor: 3 Sit and reach: 2 Electromechanical: 1 Motion sensor: 1 Not reported: 1	**Pain:** VAS: 7 NPRS: 8 QVAS: 1 P4: 1 **Activity Limitation:** ODI: 10 RMDQ: 2 PSFS: 1 TAOS: 1	Range: 5mins to 24 weeks Median: 4 weeks IQR: 3 (2.5-5.5) weeks
	Flexion EMG variables (2 studies(Dankaerts et al., 2007; Moore et al., 2015))	Range: 1 to 9 Median: 1 IQR: 4 (1-5)	sEMG (flexion-relaxation of lumbar paraspinal muscles): 2 sEMG (Onset/offset of transverse fibres of internal oblique muscles): 1	**Pain:** NRS: 3 **Activity Limitation:** ODI: 1	Range: 5 to 24 weeks Median: 24 weeks IQR: 9.5 (14.5-24) weeks
	Flexion velocity & rhythm. (1 study(Dankaerts et al., 2007))	1	Electromechanical: 1	**Pain:** NRS: 1 **Activity Limitation:** ODI: 1	24 weeks
Extension range of motion (peak). (10 studies(Acosta-Rua et al., 2008; Callahan, 1993; Hwang-Bo & Lee, 2011; Lee, 2017; Leonard et al., 2001; Lopes et al., 2019; Maluf et al., 2000; Monie et al., 2016; Stanford, 2002; Yoo, 2014))		Range: 1 to 2 Median: 1 IQR: 0 (1-1)	Inclinometer: 7 Motion sensors: 1 Not reported: 2	**Pain:** VAS: 6 NRS: 8 **Activity Limitation:** ODI: 6 RMDQ: 1 TAOS: 1	Range: 3 days to 12 weeks Median: 3.5 weeks IQR: 3.6 (1.1-4.7)
Lateral Flexion range of motion (peak) (10 studies(Acosta-Rua et al., 2008; Callahan, 1993; Floto, 2004; Hwang-Bo & Lee, 2011; Johansson & Lindberg, 1995; Leonard et al., 2001; Lopes et al., 2019; Maluf et al., 2000; Monie et al., 2016; Stanford, 2002))		Range: 1 to 2 Median: 1 IQR: 0 (1-1)	Inclinometer or goniometer: 6 Finger-tip-floor: 3 Motion sensor: 1	**Pain:** VAS: 5 NRS: 3 Pain section of RAND SF-36: 1 **Activity Limitation:** ODI: 4 RMDQ: 1 TAOS: 1	Range: 3 days to 46 weeks Median: 5 weeks IQR: 4.5 (3.5-8)

Movement category (and parameter if applicable)	Sample size (n)	Movement measurement tools (number of studies)	Pain/activity limitation measurement tools (number of studies)	Time between measurements
Rotation range of motion (peak) (4 studies(Acosta-Rua et al., 2008; Hwang-Bo & Lee, 2011; Lee, 2017; Leonard et al., 2001))	Range: 1 to 1 Median: 1 IQR: 0 (1-1)	Dual inclinometer: 2 Goniometer: 1 Not reported: 1	**Pain:** VAS: 3 **Activity Limitation:** ODI: 4	Range: 3 days to 4 weeks Median: 2.2 weeks IQR: 2.6 (0.4-3) weeks
Other (4 studies(Ikeda & McGill, 2012; Jones & Wolf, 1980; Monie et al., 2016; Wolf et al., 1982)) - Lumbar angle during squat, jump, heel drop - sEMG during painful positions - Range of motion of quadrants - sEMG differences during trunk rotation	Range: 1 to 2 Median: 1 IQR: 0.25 (1-1.25)	Vicon: 1 sEMG: 2 Motion sensor: 1	**Pain:** NRS:1 VAS: 2 McGill: 2 **Activity Limitation:** RMDQ: 1	Range: within session to 7 weeks Median: 5 days IQR: 3.5 (0.4-3.9) weeks

Abbreviations: NPRS, Numerical Pain Rating Scale; RMDQ, Roland Morris Disability Questionnaire; ODI, Oswestry Disability Index; P4, 4-item pain intensity measure; sEMG, Electromyography (surface); IQR, Inter Quartile Range (1st quartile – 3rd quartile); VAS, Visual Analogue Scale (for pain intensity); QVAS, Quadruple Visual Analogue Scale; PSFS, Patient Specific Functional Scale, LBP, Low Back Pain; TAOS, Therapeutic Associates Outcome System; RAND SF-36, Research and Development 36-Item Short Form Health Survey.

4.7.3 Summary of relationships

Table 4.3 Summary of relationships. Systematic review: Single-case designs

Summary of results about a relationship between change in movement and change in pain or activity limitation.

Movement category (And parameter if applicable)		Movement and **pain**		Movement and **activity limitation**	
		n of times investigated	n supporting relationship*	n of times investigated	n supporting relationship*
Flexion	Flexion ROM	19(Callahan, 1993; Caneiro et al., 2013; Dankaerts et al., 2007; George et al., 2004; Hwang-Bo & Lee, 2011; Lee, 2017; Leonard et al., 2001; Lopes et al., 2019; Louw et al., 2012; Maluf et al., 2000; Monie et al., 2016; Moore et al., 2015; Ohtsuki, 2014; Robinson, 2016; Stanford, 2002; Takasaki & May, 2018; Yoo, 2014)	11.7 (11.7↑,0↓)	14(Acosta-Rua et al., 2008; Caneiro et al., 2013; Dankaerts et al., 2007; George et al., 2004; Hwang-Bo & Lee, 2011; Lee, 2017; Leonard et al., 2001; Louw et al., 2012; Maluf et al., 2000; Monie et al., 2016; Moore et al., 2015; Robinson, 2016; Stanford, 2002; Takasaki & May, 2018)	6.7 (6.7↑, 0↓)
	EMG (i.e., FRR)	3(Dankaerts et al., 2007; Moore et al., 2015)	2.3 (2.3↑,0↓)	3(Dankaerts et al., 2007; Moore et al., 2015)	2.3 (2.3↑,0↓)
	Velocity & rhythm	1(Dankaerts et al., 2007)	1(1↑,0↓)	1(Dankaerts et al., 2007)	1(1↑,0↓)
Extension ROM		9(Callahan, 1993; Hwang-Bo & Lee, 2011; Lee, 2017; Leonard et al., 2001; Lopes et al., 2019; Maluf et al., 2000; Monie et al., 2016; Stanford, 2002; Yoo, 2014)	7 (7↑,0↓)	7(Acosta-Rua et al., 2008; Hwang-Bo & Lee, 2011; Lee, 2017; Leonard et al., 2001; Maluf et al., 2000; Monie et al., 2016; Stanford, 2002)	5.5 (5.5↑,0↓)
Lateral flexion ROM		8(Callahan, 1993; Hwang-Bo & Lee, 2011; Johansson & Lindberg, 1995; Leonard et al., 2001; Lopes et al., 2019; Maluf	5.5 (5.5↑,0↓)	7(Acosta-Rua et al., 2008; Floto, 2004; Hwang-Bo & Lee, 2011; Leonard et al., 2001; Maluf et al., 2000; Monie	5.5 (4.5↑,1↓)

Movement category (And parameter if applicable)	Movement and **pain**		Movement and **activity limitation**	
	n of times investigated	n supporting relationship*	n of times investigated	n supporting relationship*
	et al., 2000; Monie et al., 2016; Stanford, 2002)		et al., 2016; Stanford, 2002)	
Rotation ROM	3(Hwang-Bo & Lee, 2011; Lee, 2017; Leonard et al., 2001)	2.5 (2.5↑,0↓)	4(Acosta-Rua et al., 2008; Hwang-Bo & Lee, 2011; Lee, 2017; Leonard et al., 2001)	2.5 (2.5↑,0↓)
Other†	4(Ikeda & McGill, 2012; Jones & Wolf, 1980; Monie et al., 2016; Wolf et al., 1982)	3.5 (2.91↑,0.58↓)	1(Monie et al., 2016)	0.5 (0.25↑,0.25↓)

Abbreviations: ROM, Range of motion; EMG, Electromyography (higher value = greater relaxation (reduced muscle activity during task)); FRR, Flexion-Relaxation Ratio (higher value = greater muscle relaxation during peak flexion); ↑, an increase in that parameter was related to an improvement in pain or activity limitation; ↓, a decrease in that parameter was related to an improvement in pain or activity limitation.

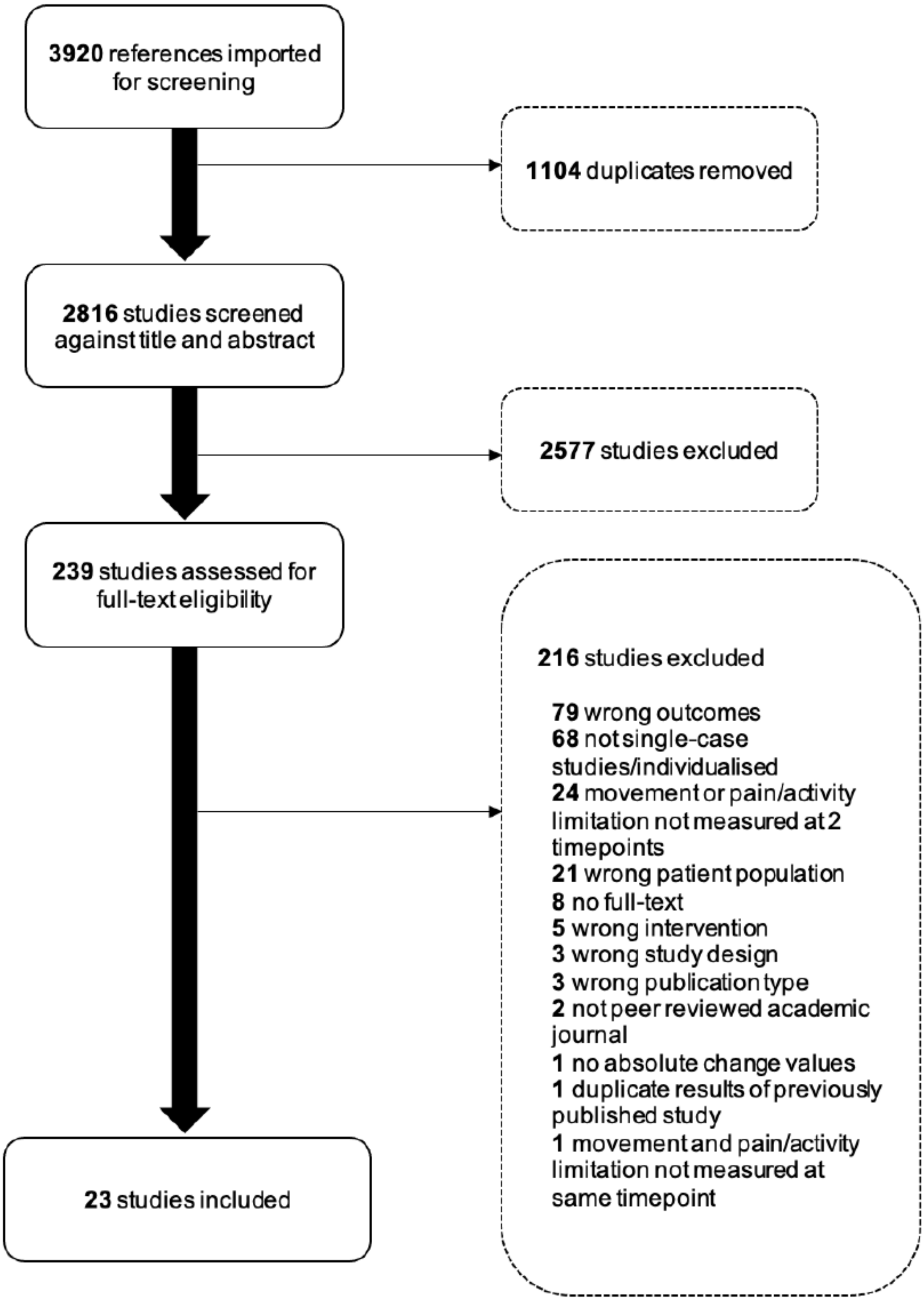
* Vote counting system – 1.0 vote per parameter. For studies that used multiple measures for a single movement parameter, the 1 vote was divided by the total number of measures used. For example, if a study only used an inclinometer to measure flexion range of motion, and that parameter showed a relationship, the vote from that study was 1.0. However, if that study had also utilised 3 other methods of flexion range of motion measurement, and only the inclinometer measurement showed a relationship, the vote from that study would be 0.25. The vote was also divided by the proportion of participants that showed a relationship. Direction of arrow represents the direction the movement parameter changed when there was an improvement in the outcome (reduced pain or activity limitation) for example, an up arrow (↑) refers to a negative relationship (as movement variable increases, pain or activity limitation decreases), and a down arrow (↓) represents a positive relationship (as movement variable decreases, pain or function also decreases).

† Other parameters included: lumbar position during squat, jump, heel drop, lumbar muscle sEMG activity during painful body movements, quadrant measures (e.g., flexion + lateral flexion) and difference between left and right paraspinal sEMG during left and right rotation.

4.8 Figures

4.8.1 PRISMA flow diagram

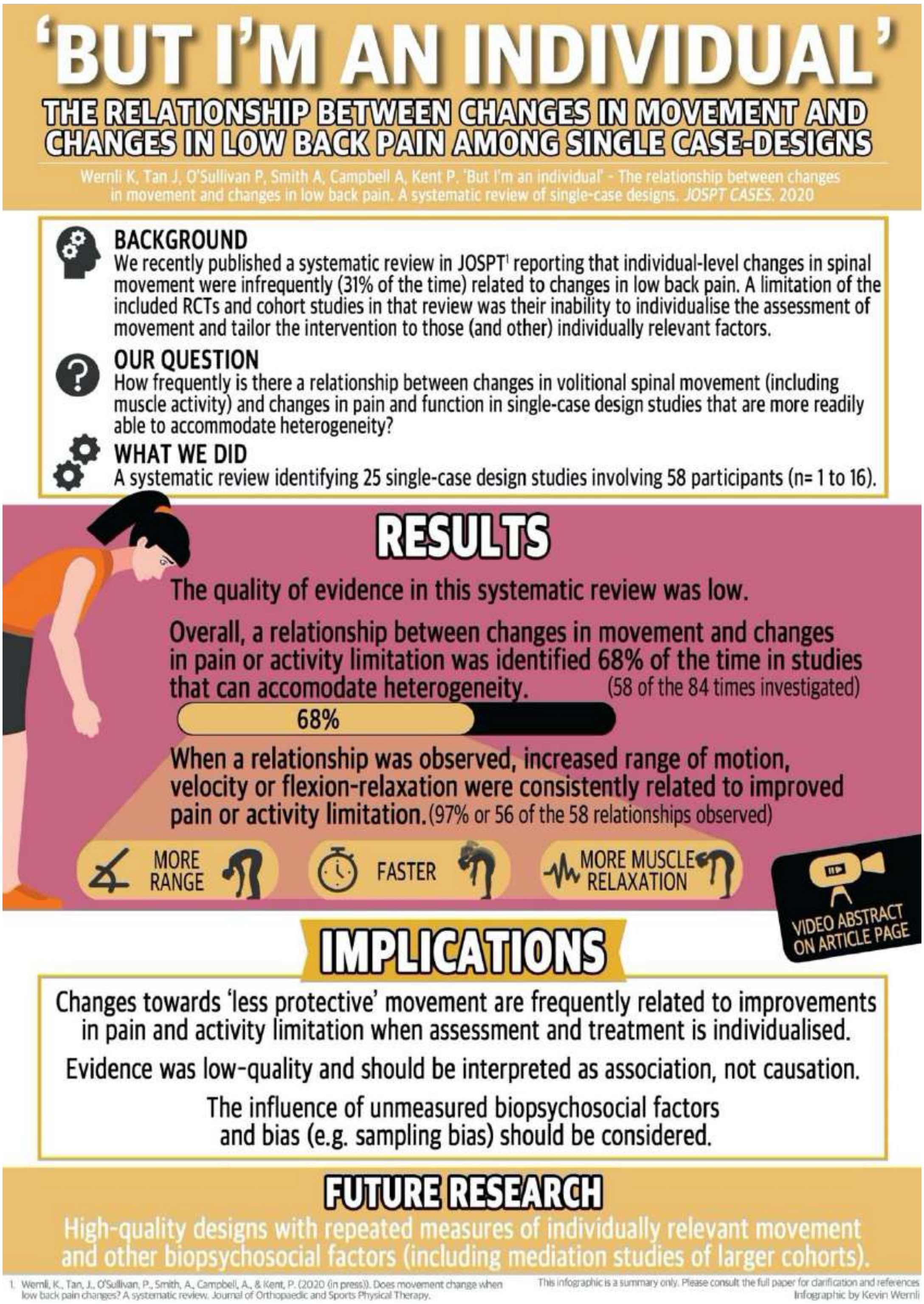
Figure 4-1 PRISMA flow diagram. Systematic review: Single-case designs



4.8.2 Infographic

Infographic. Systematic review: single-case designs.

An infographic summarising the results to facilitate dissemination of the findings.



4.9 Chapter 4 Appendices

4.9.1 Appendix 1. Search Strategy

Table 4.4 Appendix 1. Search strategy. Systematic review: Single-case designs

Search strategy used in the Medline database (adapted in other databases).

1	Case reports/
2	(case report* or case series or case-series or single-case report).ti,ab,pt.
3	1 or 2
4	Low back pain/
5	(Low* back pain or low* back ache or low* backache or lumbar pain or lumbar spin* pain or backache or lumbago or low* back dysfunction or spondylosis or dorsalgia or back strain or back pain or spin* pain or low* back syndrome or lumbopelvic pain or lumbo-pelvic pain or NSLBP or CLBP or NSCLBP or persistent low* back pain or PLBP).ti,ab.
6	4 or 5
7	exp movement/ or exp biomechanical phenomena/ or range of motion, articular/
8	(kinematic* or movement* or movement pattern* or ROM or range of motion* or range of movement* or excursion or movement control or motor control or stabilisation or stability or angle or lordosis angle or hip contribution or lumbar contribution or pelvi* contribution or position or relative position or joint position or dynamic position or dynamic posture or speed or velocity or timing or flexibility or mobility or muscle activ* or magnitude or EMG or sEMG or electromyography or electromyogram or surface electromyogra* or muscle activation patterns).ti,ab.
9	(flexion relaxation or flexion-relaxation).mp.
10	((flexion relaxation or flexion-relaxation or FR) and (ratio or response or phenomena or phenomenon)).ti,ab.
11	or/7-10
12	3 and 6 and 11
13	exp animals/ not humans.sh.
14	12 not 13
15	reliability.ti. or cross-sectional.pt. or cross-sectional.pt. or pregnancy.ti,ab.
16	spinal neoplasms/
17	(cauda equin* or cancer or metastasis or metabolic disorder or neuropathy or surg* or fracture*).mp.
18	15 or 16 or 17
19	14 not 18
20	limit 19 to English language

4.9.2 Appendix 2. Study selection criteria

Table 4.5 Appendix 2. Study selection criteria. Systematic review: Single-case designs

Inclusion	Exclusion

• Non-specific low back pain (pain between the 12th thoracic vertebra and gluteal folds).
• No restriction on duration of low back pain.
• Non-surgical or non-pharmacological intervention (cognitive, behavioural, physical or of a combined nature targeting the body and/or mind).
• Participants >12 years old.
• Peer reviewed article.
• Report individual-level data for both movement and pain or activity limitation in absolute (raw) values at ≥ 2 timepoints.
• Single-case designs (including case-series) that accommodated participant heterogeneity
• Spinal movement measured via instrumented technique and objectively quantified.
• Spinal movement included:
  o Lumbopelvic kinematics (e.g., lumbar flexion/extension angle, lumbar flexion range during functional tasks, lumbar contribution to flexion, velocity and timing of lumbar kinematics)
  o Muscle activity (e.g., flexion-relaxation phenomenon, lumbopelvic muscle activity during volitional movement).
	• Studies including pregnant woman.
	• Specific pathology (e.g., spinal malignancy, infection, fracture, cauda-equina syndrome, metabolic or spinal inflammatory disorders, nerve compression).
	• Parameters that were not related to spinal movement (e.g., gait, proprioception, muscle timing, cross-sectional area during static positions, or feedforward onset in response to alternate limb movement).
	• Studies not in the English language.

4.9.3 Appendix 3. Risk of Bias tool

Table 4.6 Appendix 3. Critical appraisal tool. Systematic review: Single-case design

Risk of Biasa tool adapted from the Joanna Briggs Institute Critical Appraisal Tool for Case Reports. Each item scored: 'Yes, No, Unclear or Not Applicable'.

Risk of Bias Item	Description
1. Were the **demographic** and **clinical characteristics** of the participants adequately described?	Description of the participants adequate enough to understand how generalisable (externally valid) the findings might be to other settings.
2. Were the **movements** assessed in a **standardised** and **valid** way?*	The study clearly describes the method of measurement of movements. Assessing validity requires that a 'pseudo-gold standard' is available with which the measure has been compared or that construct, and concurrent validity have been quantified in some other way. Measure needs to be well described and referenced unless it is well known.
3. Were **movements assessed** in a **reliable** way?*	In this context, reliability (reproducibility) refers to the quantification of test-retest variability. The measure needs to be well known, or if not well known, it needs to be referenced.
4. Were **pain** and/or **activity limitation** assessed in a **standardised** and **valid** way?*	The study should clearly describe the method of measurement of pain and/or activity limitation. Validity requires some demonstration (for example a reference) of construct and concurrent validity.
5. Were **pain** and/or **activity limitation** assessed in a **reliable** way?*	Reliability refers here to the quantification of test-retest variability. The method of measurement needs to be well known, or if not well known it needs to be referenced.
6. Was the assessment of movement (and its change) **blind** to the **assessment** of pain or activity limitation (and its change) or vice-versa?*	Assessor knowledge of participant self-report of pain or activity limitation (or its change) may have biased the assessor's subsequent assessment of movement (or vice-versa). If assessor blinding is reported, a '1 - yes' is scored; if the non-blinding of assessors is reported, a '0 – no' is scored; and if it is not clear if blinding of assessors took place, a 'U – Unclear' is scored.

[a] Our aim was to determine the frequency a change in movement was related to a change in pain or activity limitation. Therefore, the most important sources of bias were related to how well the demographic and clinical characteristics were described (to establish how generalisable to findings would be), the validity and reliability of the tools used to measure movement, pain and activity limitation, and the presence of assessor blinding.
* Critical risk of bias

4.9.4 Appendix 4. GRADE assessment and reasoning

The GRADE guidelines suggest starting at 'low-quality' for research using single-case designs. We used the other GRADE criteria to upgrade or downgrade the quality score in relation to our research question.

Domain 1. Risk of bias
Twenty-four out of 25 (96%) studies included in this review were categorised as high risk of bias, predominantly due to uncertainty about the blinding of assessors because this aspect was unreported. Additionally, the potential for selective recruitment of participants (sampling bias) among single-case design studies further reduces our confidence about minimisation of the influence of bias. We deemed this as a significant threat and therefore downgraded the quality of evidence from low to very low for this domain.

Domain 2. Imprecision
Low participant numbers and the use of movement measurement tools with uncertain within- and between-session error (despite most studies providing references for the use of their assessment tools), resulted in some lack of confidence in identifying *true change.* We did not deem this significant enough to warrant any additional change to the rating.

Domain 3. Inconsistency
Despite frequently identifying relationships amongst both pain and activity limitation outcomes, and the very consistent findings regarding the direction of movement change in the presence of a relationship (97%), the substantial heterogeneity of populations, interventions and methodology amongst the included studies resulted in some lack of confidence in the quality of evidence for the inconsistency domain. We did not deem this significant enough to warrant any additional change to the rating.

Domain 4. Indirectness
The prevalent use of study designs that were readily able to measure salient movement parameters and individualise the intervention increases our confidence that the included studies were able to investigate the relationship directly. This resulted in an upgrading of the overall quality of evidence from very low to low.

Domain 5. Publication bias.
The potential for selective publication of studies that show changes in movement, pain, or activity limitation would over-estimate the presence of a relationship. However, we included studies that did not directly target movement, which may minimise the influence of any potential over-estimation. Nevertheless, our certainty that the findings are free from the influence of publication bias is low. We did not deem this significant enough to warrant any additional change to the rating.

Additional criteria which could influence a decision to upgrade the quality rating:
1. Large effect
Not applicable to this systematic review.

2. Dose Response
Not applicable to this systematic review.

3. Accounted for all plausible residual confounding
Not applicable to this systematic review.

Summary:
Starting with a GRADE of 'low-quality' for single-case designs, after consideration of all GRADE criteria, we maintained the classification of low-quality evidence. Defined by GRADE as "our confidence in the effect estimate is limited: The true effect may be substantially different from the estimate of the effect".

For our research question about a relationship between change in clinical attributes, our confidence in the findings was reduced due to the potential lack of assessor blinding and influence of selective reporting, however this was countered by the strong ability of studies to directly investigate the relationship.

References for quality of evidence assessment:
Guyatt, G. H., Oxman, A. D., Vist, G. E., Kunz, R., Falck-Ytter, Y., Alonso-Coello, P., & Schünemann, H. J. (2008). GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. *British Medical Journal, 336*(7650), 924-926. https://doi.org/10.1136/bmj.39489.470347.AD

Balshem, H., Helfand, M., Schunemann, H. J., Oxman, A. D., Kunz, R., Brozek, J., Vist, G. E., Falck-Ytter, Y., Meerpohl, J., Norris, S., & Guyatt, G. H. (2011). GRADE guidelines: 3. Rating the quality of evidence. *Journal of Clinical Epidemiology, 64*(4), 401-406. https://doi.org/10.1016/j.jclinepi.2010.07.015

Siemieniuk, R., & Guyatt, G. (2019). *What is GRADE?* British Medical Journal. Retrieved 22 May, from https://bestpractice.bmj.com/info/us/toolkit/learn-ebm/what-is-grade/

4.9.5 Appendix 5. Results from individual studies

Table 4.7 Appendix 5. Results from individual studies. Systematic review: Single-case designs

Author & year	n	Measu-rement Tool	Length of LBP (Mean (±SD) if available)	Time between measures	Movement		Pain			Activity Limitation			Study that reported minimal detectable change value (if applicable and not provided in paper)
					Pre	Post	Pre	Post	Related?	Pre	Post	Related?	
FLEXION RANGE OF MOTION STUDIES (PEAK)													
Acosta-Rua 2008	1	BROM-II (dual inclinometer)	More than 6 weeks	4 weeks	90°	90°				34% ODI	2% ODI	No relationship	
Dankaerts 2007	1	3space Fastrak	2 years	6 months	48°	47°	4/10 NPRS	0/10 NPRS	No relationship	34% ODI	2% ODI	No relationship	
Hwang-Bo 2011	1	Back ROM device	Acute	3 days	8°	80°	8/10 VAS	0/10 VAS	**Yes**	72% ODI	0% ODI	**Yes**	
Maluf 2000	1	Dual inclinometer	40-year history, current episode 10 weeks	3 months	30°	80°	6/10 NPRS	3/10 when present (75-80% of week was painfree)	**Yes**	43% ODI	16% ODI	**Yes**	
Monie 2016	2	MotionStarTM sensors	Acute exacerbations	1: 2 days 2: 8 days	1: 49.1° 2: 19.1°	1: 50.5° 2: 38.2°	1: 5.2 VAS 2: 8.6 VAS	1: 0.5 VAS 2: 0.2 VAS	1: No **2: Yes**	1: 7.0 RMDQ 2: 20.0 RMDQ	1: 4 RMDQ 2: 5 RMDQ	1: No **2: Yes**	Maughan EF (2010) Eur. Spine J. 19(9):1484. Monie AP (2015) Clin Biomech. 30(6):558
Yoo 2014	1	Dual Inclinometer	1 year	2 weeks	58°	59°	7/10 VAS	4/10 VAS	**Yes**				
Lee 2017	1	NA	Acute	3 days	15°	77°	6/10 VAS	0/10 VAS	**Yes**	70% ODI	0%ODI	**Yes**	
Lopes 2019	1	Goniometer	3 years	5 weeks	42°	62°	8/10 VAS	0/10 VAS	**Yes**				Akizuki K et al. (2016) J of PT Science
Takasaki 2019	1	Fingertip-floor	Intermittent	6 weeks	-15.1cm	-16cm	14/40 P4	0/40 P4	No	ODI: 12% PSFS: 6.8/10 (10 = less disability)	ODI: 0% PSFS: 10/10	No	
Callahan 1992	1	Fingertip-floor	2 years and 5 months	8 weeks	10 inches from floor	4 inches from floor	6/10 NRS	3/10 NRS	**Yes**				

Author & year	n	Measu-rement Tool	Length of LBP (Mean (±SD) if available)	Time between measures	Movement		Pain			Activity Limitation			Study that reported minimal detectable change value (if applicable and not provided in paper)
					Pre	Post	Pre	Post	Related?	Pre	Post	Related?	
Caneiro 2013	1	Sit and reach	4 months	8 weeks	-0.12m	0m	7/10 NPRS	1/10 NPRS	**Yes**	RMDQ:12 PSFS: 1.33	RMDQ:1 PSFS: 8.67	**Yes**	
George 2004	1	Single bubble goniom eter	2 weeks	4 weeks	95°	95°	6/10 present 9/10 worst 3/10 best	1/10 present 2/10 worst 0/10 best	No	52% ODI	16% ODI	No	
Leonard 2001	1	Goniom eter	15 years	3 weeks	78°	98°	4.25/10 NRS	2/10 NRS	**Yes**	42% ODI	24% ODI	**Yes**	
Louw 2012	1	Inclinom eter	3 years	45mins post session	10°	72°	9/10	8/10	No	54% ODI	54% ODI	No	
Moore 2015	9	Sit and reach	9.4 (7.8) years	5 weeks	(cm): 1: 13 2:33 3:1 4:1 5:40 6:31 7:24 8:11 9:19	(cm): 1: 28.5 2:36.5 3:7 4:8 5:39 6:36 7:27 8:21 9:18	(NPRS): 1: 6 2:4 3:2 4:5 5:6 6:5 7:6 8:4 9:4	(NPRS): 1: 6 2:1 3:1 4:4 5:6 6:1 7:4 8:0 9:3	**2/9 had clinically important improvement in both.**	(ODI): 1: 22 2:34 3:32 4:26 5:14 6:10 7:8 8:16 9:22	(ODI): 1: 16 2:10 3:8 4:18 5:14 6:4 7:12 8:0 9:26	**2/9 had clinically important improvement in both.**	
Ohstuki 2014	1	Fingerti p-floor	Acute	4 weeks	15cm	5cm	85/100 VAS	0/100 VAS	**Yes**				
Robinson 2016	1	Inclinom eter	6 weeks	4 weeks	10°	45°	9/10 NPRS	1/10 NPRS	**Yes**	24/50 mODI	20/50 mODI	No	
Stanford 2002	1	Inclinom eter	4 months	4 weeks	10°	30°	7.1/10 VAS	0.4/10 VAS	**Yes**	42% TAOS	84% TAOS	**Yes**	
FLEXION EMG STUDIES													
Dankaerts 2007	1	sEMG (Onset, offset, onset pattern of transver se fibres of internal oblique)	2 years	6 months	No clear onset-offset-onset pattern of transverse fibres of Internal oblique	More normal onset-offset-onset pattern of transverse fibres of internal oblique	4/10 NPRS	0/10 NPRS	**Yes. Relationship observed**	34% ODI	2% ODI	**Yes. Relationship observed**	
Dankaerts 2007	1	sEMG (FRR)	2 years	6 months	Increased muscle activity with no flexion relaxation	More normal sEMG pattern with an FRP	4/10 NPRS	0/10 NPRS	**Yes. Relationship observed**	34% ODI	2% ODI	**Yes. Relationship observed**	

Author & year	n	Measu-rement Tool	Length of LBP (Mean (±SD) if available)	Time between measures	Movement		Pain			Activity Limitation			Study that reported minimal detectable change value (if applicable and not provided in paper)
					Pre	Post	Pre	Post	Related?	Pre	Post	Related?	
					during forward bending								
Moore 2015	9	sEMG (extension relaxation ratio)	9.4 (7.8) years. Range 2-25 years	5 weeks	Extension relaxation ratio: 1: 3.2 2: 1.9 3: 2.2 4: 1.7 5: 1.8 6: 1.7 7: 1.3 8: 1.2	Extension relaxation ratio: 1: 4 2: 3.5* 3: 1.3 4: 2.4 5: 1.3 6: 1.6 7: 2.5* 8: 6.5* 9: 1.6	NPRS: 1: 6 2: 4 3: 2 4: 5 5: 6 6: 5 7: 6 8: 4 9: 4	NPRS: 1: 6 2: 1* 3: 1 4: 4 5: 6 6: 1* 7: 4* 8: 0* 9: 3	3/3 who had clinically important improvement in FRR also had clinically important improvement in Pain. 3/4 who had clinically important improvement in Pain also had clinically important improvement in FRR.	ODI: 1:22 2:34 3:32 4:26 5:14 6:10 7:8 8:16 9:22	ODI: 1:16 2:10* 3:8* 4:18 5:14 6:4 7:12 8:0* 9:26	2/3 who had clinically important improvement in FRR also had clinically important improvement in AL. 2/3 who had clinically important improvement in AL also had clinically important improvement in FRR.	
FLEXION VELOCITY/LUMBOPELVIC RHYTHM STUDIES													
Dankaerts 2007	1	3Space Fastrak (lumbopelvic rhythm)	2 years	6 months	Curve reversal between 3rd and 4th quartile	Curve reversal between 2nd and 3rd quartile	4/10 NPRS	0/10 NPRS	**Yes. Relationship observed**	34% ODI	2% ODI	**Yes. Relationship observed**	
EXTENSION RANGE OF MOTION STUDIES (PEAK)													
Acosta-Rua 2008	1	BROM-II (dual inclinometer)	More than 6 weeks	4 weeks	30°	30°				34% ODI	2% ODI	No relationship	
Hwang-Bo 2011	1	Back ROM device	Acute	3 days	7°	28°	8/10 VAS	0/10 VAS	**Yes**	72% ODI	0% ODI	**Yes**	
Maluf 2000	1	Dual inclinometer	40-year history, current episode 10 weeks	3 months	8°	45°	6/10 NPRS	3/10 when present (75-80% of week was painfree)	**Yes**	43% ODI	16% ODI	**Yes**	
Monie 2016	2	MotionStarTM sensors	Acute exacerbations	1: 2 days 2: 8 days	1: 13.6° 2: 11.3°	1: 23.4° 2: 19.3°	1: 5.2 VAS 2: 8.6 VAS	1: 0.5 VAS 2: 0.2 VAS	1: No **2: Yes**	1: 7.0 RMDQ 2: 20.0 RMDQ	1: 4 RMDQ 2: 5 RMDQ	1: No **2: Yes**	Maughan EF (2010) Eur. Spine J. 19(9):1484.

Author & year	n	Measu-rement Tool	Length of LBP (Mean (±SD) if available)	Time between measures	Movement		Pain			Activity Limitation			Study that reported minimal detectable change value (if applicable and not provided in paper)
					Pre	Post	Pre	Post	Related?	Pre	Post	Related?	
													Monie AP (2015) Clin Biomech. 30(6):558
Yoo 2014	1	Dual Inclinometer	1 year	2 weeks	32°	43°	7/10 VAS	4/10 VAS	**Yes**				
Callahan 1992	1	Not reported	2 years and 5 months	8 weeks	35°	40°	6/10 NRS	3/10 NRS	No. Movement did not exceed MDC				Kobler MJ (2013) Int J Sports Phys Ther. 8(2):129
Lee 2017	1	NA	Acute	3 days	12°	27°	6/10 VAS	0/10 VAS	**Yes**	70% ODI	0%ODI	**Yes**	
Leonard 2001	1	Goniometer	15 years	3 weeks	12° (estimated from graph)	22° (estimated from graph)	4.25/10 NRS	2/10 NRS	**Yes**	42% ODI	24% ODI	**Yes**	Kobler MJ (2013) Int J Sports Phys Ther. 8(2):129
Lopes 2019	1	Goniometer	3 years	5 weeks	18°	22°	8/10 VAS	0/10 VAS	No				Akizuki K et al. (2016) J of PT Science
Stanford 2002	1	Inclinometer	4 months	4 weeks	8	15	7.1/10 VAS	0.4/10 VAS	**Yes**	42% TAOS	84% TAOS	**Yes**	Kobler MJ (2013) Int J Sports Phys Ther. 8(2):129
LATERAL FLEXION RANGE OF MOTION STUDIES (PEAK)													
Monie 2016	2	MotionStarTM sensors	Acute exacerbations	1: 2 days 2: 8 days	1: RLF: 9.9°, LLF:11.3° 2: RLF 2.3°, LLF:2.5°	1: RLF: 12.9°, LLF:15.0° 2: RLF 21.3°, LLF:14.2°	1: 5.2 VAS 2: 8.6 VAS	1: 0.5 VAS 2: 0.2 VAS	1: No **2: Yes**	1: 7.0 RMDQ 2: 20.0 RMDQ	1: 4 RMDQ 2: 5 RMDQ	1: No **2: Yes**	Maughan EF (2010) Eur. Spine J. 19(9):1484 Monie AP (2015) Clin Biomech. 30(6):558
Acosta-Rua 2008	1	BROM-II (dual inclinometer)	More than 6 weeks	4 weeks	RLF:8° LLF:8°	RLF:16° LLF:16°				34% ODI	2% ODI	**Yes**	Kolber MJ et al. (2013) Int J Sports Phys Ther. 8(2): 129-137
Hwang-Bo 2011	1	Back ROM device	Acute	3 days	RLF:5° LLF:5°	RLF:33° LLF:35°	8/10 VAS	0/10 VAS	**Yes**	72% ODI	0% ODI	**Yes**	
Maluf 2000	1	Dual inclinometer	40-year history, current episode 10 weeks	3 months	RLF:34° LLF:32°	RLF:31° LLF:24°	6/10 NPRS	3/10 when present (75-80% of week was painfree)	**Yes**	43% ODI	16% ODI	**Yes**	
Callahan 1992	1	Fingertip-floor	2 years and 5 months	8 weeks	RLF: 22inch LLF: 22.25inch	RLF:19.25inch LLF:20inch	6/10 NRS	3/10 NRS	No				Strand et al. (2011) Phys Ther 91(3):404-15

Author & year	n	Measu-rement Tool	Length of LBP (Mean (±SD) if available)	Time between measures	Movement		Pain			Activity Limitation			Study that reported minimal detectable change value (if applicable and not provided in paper)
					Pre	Post	Pre	Post	Related?	Pre	Post	Related?	
Floto 2004	1	Fingertip-floor	1 year	8 weeks	RLF: 1inch above knee LLF: 1.5inch above knee	RLF: 1inch above knee LLF: 1.5inch above knee				80% ODI	44% ODI	No. No change to RLF	
Johansson 1995	1	Fingertip-floor	1 year	46 weeks	NA	NA	During baseline: AM: 1.9(0.9) Noon: 1.4(0.8) PM: 1.6(1.1) Bed: 1.4(0.5)	End of treatment: 1.8(0.7) 0.6 (0.6)* 1.1 (0.8)* 1.1 (0.7)*	No. Changes in movement did not exceed the measurement error which was estimated in the inter and intra-tester reliability assessments				
Leonard 2001	1	Goniometer	15 years	3 weeks	R & L: 24° - estimated from graph	R & L: 35° - estimated from graph	4.25/10 NRS	2/10 NRS	**Yes**	42% ODI	24% ODI	**Yes**	Kolber MJ et al. (2013) Int J Sports Phys Ther. 8(2): 129-137
Lopes 2019	1	Goniometer	3 years	5 weeks	R & L: 21°	RLF: 35° LLF: 33°	8/10 VAS	0/10 VAS	**Yes**				Akizuki K et al. (2016) J of PT Science
Stanford 2002	1	Goniometer	4 months	4 weeks	R & L: 10°	RLF: 25° LLF: 26°	7.1/10 VAS	0.4/10 VAS	**Yes**	42% TAOS	84% TAOS	**Yes**	
ROTATION RANGE OF MOTION STUDIES (PEAK)													
Acosta-Rua 2008	1	BROM-II (dual inclinometer)	More than 6 weeks	4 weeks	RROT:2° LROT:2°	RROT:6° LROT:6°				34% ODI	2% ODI	No	Furness J et al. (2018) PeerJ 6(e4431)
Hwang-Bo 2011	1	Back ROM device	Acute	3 days	RROT:5° LROT:5°	RROT:27° LROT:25°	8/10 VAS	0/10 VAS	**Yes**	72% ODI	0% ODI	**Yes**	
Lee 2017	1	NA	Acute	3 days	RROT:25° LROT:15°	RROT:45° LROT:43°	6/10 VAS	0/10 VAS	**Yes**	70% ODI	0%ODI	**Yes**	
Leonard 2001	1	Goniometer	15 years	3 weeks	RROT:20° LROT:25° *estimated from graph	RROT:36° LROT:36° *estimated from graph	4.25/10 NRS	2/10 NRS	**Yes RROT (>Smallest detectable change).** No LROT (<SDC)	42% ODI	24% ODI	**Yes RROT (>Smallest detectable change).** No LROT (<SDC)	Furness J et al. (2018) PeerJ 6(e4431)
OTHER MOVEMENT PARAMETERS													

Author & year	n	Measu-rement Tool	Length of LBP (Mean (±SD) if available)	Time between measures	Movement		Pain			Activity Limitation			Study that reported minimal detectable change value (if applicable and not provided in paper)
					Pre	Post	Pre	Post	Related?	Pre	Post	Related?	
Ikeda 2012	1	Vicon, forceplate, EMG	NA	Within session	Squat: -15.7° Jump: -2.5° Heel drop: 1.07°	Squat: --3.7° Jump: -5° Heel drop: -1.86°	Squat: 6/10 Jump: 7/10 Heel drop: 5/10	Squat: 0/10 Jump: 0/10 Heel drop: 0/10	**Yes. Changes considered biologically significant 3 out of 3 tasks**				
Jones 1980	1	EMG	2 years	10 weeks	25.6uV	8.15uV	McGill: 2.4 Pain before session: 13.5/100 VAS Pain after session: 18.5/100	McGill: 1.5 Pain before session:6/100 Pain after session: 6/10	**Yes. Cross correlation revealed r = 0.23, p = 0.02. Performed by KW**				
Monie 2016	2	MotionStarTM sensors	1: Acute 2: Acute	1: 2 days 2: 8 days	P1: FwRLF: 51.2°, FwLLF: 49.4°, EwRLF: 5° EwLLF:8.9° P2: FwRLF: 10.9°, FwLLF: 9.8°, EwRLF: 9.6° EwLLF:11.9°	P1: FwRLF: 39.6°, FwLLF: 39.4°, EwRLF: 10.6° EwLLF:13.5° P2: FwRLF: 31.2°, FwLLF: 27.5°, EwRLF: 16.5° EwLLF:14.2°	P1: 5.2/10 P2: 8.6/10 VAS	P1: 0.5/10 P2: 0.2/10 VAS	**P1: FwRLF: 11.6Degree REDUCTION (above Least significant change) EVIDENCE OF INVERSE RELATION (less ROM better) FwLLF: 10 degree REDUCTION (above least significant change) EVIDENCE OF INVERSE RELATION (less ROM better)** EwRLF: 5.6 degree IMPROVEMENT (BELOW least significant change) NO EVIDENCE OF RELATION EwLLF: 4.6 deg IMPROVEMENT (BELOW least	P1: 7.0 RMDQ P2: 20.0 RMDQ	P1: 4.0 RMDQ P2: 5.0 RMDQ	**P1:** NO EVIDENCE OF RELATIONSHIP **(evidence of inverse relationship in 2/4) FwRLF: 11.6Degree REDUCTION (above Least significant change) EVIDENCE OF INVERSE RELATION (less ROM better) FwLLF: 10 degree REDUCTION (above least significant change) EVIDENCE OF INVERSE RELATION (less ROM better)** EwRLF: 5.6 degree IMPROVEMENT (BELOW least significant change) NO EVIDENCE OF RELATION EwLLF: 4.6 deg IMPROVEMENT (BELOW least significant change)	Monie AP et al. (2015) Clin Biomech 30(6):558-64

Author & year	n	Measu-rement Tool	Length of LBP (Mean (±SD) if available)	Time between measures	Movement		Pain			Activity Limitation			Study that reported minimal detectable change value (if applicable and not provided in paper)
					Pre	Post	Pre	Post	Related?	Pre	Post	Related?	
									significant change) NO EVIDENCE OF RELATION **P2: FwRLF: 20.3 deg IMPROVEMENT (ABOVE LSC) EVIDENCE OF RELATION (more ROM better) FwLLF: 17.7 deg improvement (ABOVE LSC) EVIDENCE OF RELATION (more ROM better)** ExRLF: 7.1 deg improvement (BELOW LSC) NO EVIDENCE OF RELATION EwLLF: 2.3 deg improvement (BELOW LSC) NO EVIDENCE OF RELATION			NO EVIDENCE OF RELATION **P2: Evidence of relationship in 2/4 movements. FwRLF: 20.3 deg IMPROVEMENT (ABOVE LSC) EVIDENCE OF RELATION (more ROM better) FwLLF: 17.7 deg improvement (ABOVE LSC) EVIDENCE OF RELATION (more ROM better)** ExRLF: 7.1 deg improvement (BELOW LSC) NO EVIDENCE OF RELATION EwLLF: 2.3 deg improvement (BELOW LSC) NO EVIDENCE OF RELATION	
Wolf 1982	1	sEMG	5 months	7 weeks	Minimal difference between Left and Right Rotation (2uV for Left electrode pair and 1uV for Right electrode pair	Large difference between left and right rotation (8uV for Left electrode pair and 22.5uV for Right electrode pair)	9/10 McGill	0/10 McGill	**Yes, cross correlation between difference in EMG values and McGill pain was r = -0.61, p0.033 and r = -0.8, p = 0.002 for left and right electrode pair respectively. Performed by KW**				

Abbreviations: NS, Not significant; ODI, Oswestry Disability Index; VAS, Visual analogue scale, uV, Microvolts, RLF, Right lateral flexion, LLF, Left lateral flexion; RROT, Right rotation; LROT, Left rotation; Fw, Flexion with; Ew, Extension with; NRS, Numerical rating scale; RMDQ, Roland Morris Disability Questionnaire.

References for minimal detectable change value:

Maughan, E. F., & Lewis, J. S. (2010). Outcome measures in chronic low back pain. *European Spine Journal, 19*(9), 1484-1494. https://doi.org/10.1007/s00586-010-1353-6

Strand, L. I., Anderson, B., Lygren, H., Skouen, J. S., Ostelo, R., & Magnussen, L. H. (2011). Responsiveness to change of 10 physical tests used for patients with back pain. *Physical Therapy, 91*(3), 404-415. https://doi.org/10.2522/ptj.20100016

Kolber, M. J., Pizzini, M., Robinson, A., Yanez, D., & Hanney, W. J. (2013). The reliability and concurrent validity of measurements used to quantify lumbar spine mobility: an analysis of an iphone® application and gravity based inclinometry. *International journal of sports physical therapy, 8*(2), 129-137. https://www.ncbi.nlm.nih.gov/pubmed/23593551

Akizuki, K., Yamaguchi, K., Morita, Y., & Ohashi, Y. (2016). The effect of proficiency level on measurement error of range of motion. *Journal of physical therapy science, 28*(9), 2644-2651. https://doi.org/10.1589/jpts.28.2644

Furness, J., Schram, B., Cox, A. J., Anderson, S. L., & Keogh, J. (2018). Reliability and concurrent validity of the iPhone (®) Compass application to measure thoracic rotation range of motion (ROM) in healthy participants. *PeerJ, 6*, e4431-e4431. https://doi.org/10.7717/peerj.4431

4.9.6 Appendix 6. Baseline comparison

Table 4.8 Appendix 6. Baseline comparison. Systematic review: Single-case designs

Baseline pain and activity limitation comparisons between instances where a relationship was or was not identified in the included studies.

Data source	Design and outcome variable	Relationship[a]	No relationship[a]
Baseline values for studies included in this systematic review	**PAIN**	n of studies = 14	n of studies = 8
	Median pain[b] (0-100)	65/100	50/100
	IQR (LQ – UQ)	31 (49 - 80)	18 (39 - 57)
	Range (min - max)	36 - 90	35 - 90
	n per study. Median (range)	1 (1 - 9) participants	1.5 (1 - 16) participants
	ACTIVITY LIMITATION	n of studies = 9	n of studies = 9
	Median activity limitation[b] (0-100)	42/100	34/100
	IQR (LQ – UQ)	36 (34 - 70)	30 (22 - 52)
	Range (min - max)	24 - 83	15.5 - 58
	n per study. Median (range)	1 (1 - 9) participants	1 (1 - 9) participants
Baseline values for clinical trials in individuals with non-specific low back pain[c]	**Mean baseline pain**	Mean (SD): 48/100 (14) Median: 51/100	
	Mean baseline activity limitation	Mean (SD): 41/100 (12) Median: 46/100	

[a] If a study had multiple participants, only the mean baseline value for participants showing a relationship was used in the calculation for the 'relationship' group, while the mean baseline value for participants not showing a relationship in that study was used for the 'no relationship' group.
[b] Outcome measures were rescaled to a 0-100 score (100 = worst).
[c] Studies used for comparison were:

Vibe Fersum, K., O'Sullivan, P., Skouen, J. S., Smith, A., & Kvåle, A. (2013). Efficacy of classification-based cognitive functional therapy in patients with non-specific chronic low back pain: A randomized controlled trial. *European Journal of Pain, 17*(6), 916-928. https://doi.org/10.1002/j.1532-2149.2012.00252.x

Kamper, S. J., Apeldoorn, A. T., Chiarotto, A., Smeets, R. J., Ostelo, R. W., Guzman, J., & van Tulder, M. W. (2014). Multidisciplinary biopsychosocial rehabilitation for chronic low back pain. *Cochrane Database of Systematic Reviews* (9), Cd000963. https://doi.org/10.1002/14651858.CD000963.pub3

Hill, J. C., Whitehurst, D. G. T., Lewis, M., Bryan, S., Dunn, K. M., Foster, N. E., Konstantinou, K., Main, C. J., Mason, E., Somerville, S., Sowden, G., Vohora, K., & Hay, E. M. (2011). Comparison of stratified primary care management for low back pain with current best practice (STarT Back): a randomised controlled trial. *The Lancet, 378*(9802), 1560-1571. https://doi.org/10.1016/S0140-6736(11)60937-9

UK Beam Trial Team. (2004). United Kingdom back pain exercise and manipulation (UK BEAM) randomised trial: effectiveness of physical treatments for back pain in primary care. *British Medical Journal, 329*(7479), 1377. https://doi.org/10.1136/bmj.38282.669225.AE

Moffett, J. K., Torgerson, D., Bell-Syer, S., Jackson, D., Llewlyn-Phillips, H., Farrin, A., & Barber, J. (1999). Randomised controlled trial of exercise for low back pain: clinical outcomes, costs, and preferences. *British Medical Journal, 319*(7205), 279. https://doi.org/10.1136/bmj.319.7205.279

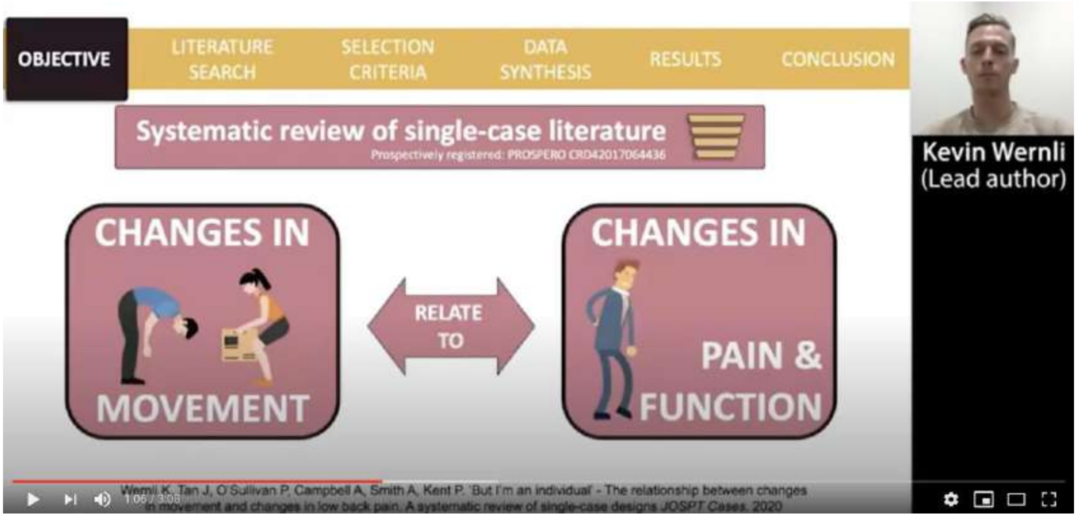
Frost, H., Moffett, J. A. K., Moser, J. S., & Fairbank, J. C. T. (1995). Randomised controlled trial for evaluation of fitness programme for patients with chronic low back pain. *British Medical Journal, 310*(6973), 151. https://doi.org/10.1136/bmj.310.6973.151

Fairbank, J., Frost, H., Wilson-MacDonald, J., Yu, L.-M., Barker, K., & Collins, R. (2005). Randomised controlled trial to compare surgical stabilisation of the lumbar spine with an intensive rehabilitation programme for patients with chronic low back pain: the MRC spine stabilisation trial. *British Medical Journal, 330*(7502), 1233. https://doi.org/10.1136/bmj.38441.620417.8F

Brinkhaus, B., Witt, C. M., Jena, S., Linde, K., Streng, A., Wagenpfeil, S., Irnich, D., Walther, H.-U., Melchart, D., & Willich, S. N. (2006). Acupuncture in Patients With Chronic Low Back Pain: A Randomized Controlled Trial. *JAMA Internal Medicine, 166*(4), 450-457. https://doi.org/10.1001/archinte.166.4.450

4.9.7 Appendix 7. Video abstract

The video abstract produced to facilitate translation of the findings of this systematic review.



Video abstract can be found at: https://youtu.be/830RoPmFcbM

Chapter 5 Movement, posture, and LBP single-case series

Movement, posture, and low back pain. How do they relate? A replicated single-case design in 12 people with persistent, disabling low back pain

The two systematic reviews presented in the previous chapters of this thesis highlight a significant lack of high-quality research investigating the longitudinal relationship between movement, posture, and LBP. There are limited studies investigating this relationship at the individual level, using individualised assessment measures, and using individualised interventions that can effectively change pain, activity limitation, movement, or posture. The following two chapters describe a single empirical study. Multiple measures of movement, posture, pain, activity limitation, and psychological factors occurred throughout the study. Additionally, up to 10 intervention sessions and two qualitative interviews also occurred. The timing, frequency, and location of these are presented in Figure 5-1 below.

Figure 5-1 Timing and frequency of data collection and treatment in the single-case series

			A: Baseline (5 weeks)					B: Intervention (12 weeks)												A: Follow up (5 weeks & 9 months)					
		Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	9m
Task	**Time**	**Location**																							
Movement assessment session	30 mins	Clinic or home	X	X	X	X	X	X	X	X	X	X	X	X	X		X		X	X	X	X	X	X	X
Treatment (up to 10 depending on clinical course)	60mins initial, 30mins follow up	Clinic						X	X	X	X	X	X	X	X		X		X						
Short online questionnaire (short form for pain, activity limitation, and psychological factors)	5 mins	Home	X	X	X	X	X	X	X	X	X	X	X	X	X		X		X	X	X	X	X	X	X
Longer online questionnaire (long form for pain, activity limitation, and psychological factors)	30 mins	Home	X				X													X					X
Qualitative Interview	30mins	Home or clinic	X																	X					

This chapter describes a repeated measures single-case series that aimed to investigate how movement, posture, pain, and activity limitation relate over time. Up to 20 measures were captured before, during, and after an intervention that has demonstrated an ability to significantly change pain and activity limitation (Cognitive Functional Therapy). This was replicated in 12 people with persistent, disabling, non-specific LBP, allowing a comprehensive investigation into this relationship. Additional materials such as participant information sheets, consent forms, recruitment materials, and questionnaires are presented in the thesis appendix (see Appendix D). This study was published in the *European Journal of Pain* and will be presented in its published format. Additional dissemination and knowledge translation materials are presented in Thesis Appendix A.1.3.

This chapter was published in the *European Journal of Pain.*

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Movement, posture, and low back pain. How do they relate? A replicated single-case design in 12 people with persistent, disabling low back pain. European Journal of Pain, 24, 1831– 1849. https://doi.org/10.1002/ejp.1631

5.1 Abstract

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ORIGINAL ARTICLE

EJP European Journal of Pain

Movement, posture and low back pain. How do they relate? A replicated single-case design in 12 people with persistent, disabling low back pain

Kevin Wernli[1,2] | **Peter O'Sullivan**[1,2] | **Anne Smith**[1] | **Amity Campbell**[1] | **Peter Kent**[1,3]

[1]School of Physiotherapy and Exercise Science, Curtin University, Perth, Western Australia, Australia

[2]Body Logic Physiotherapy, Perth, Western Australia, Australia

[3]Department of Sports Science and Clinical Biomechanics, University of Southern Denmark, Odense, Denmark

Correspondence
Kevin Wernli, School of Physiotherapy and Exercise Science, Curtin University, Building 408, Brand Drive, Bentley, Western Australia 6102, Australia.
Email: kevin.wernli@postgrad.curtin.edu.au

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Abstract

Background: Movement and posture are commonly believed to relate to non-specific low back pain (NSLBP). While people with NSLBP appear to move and posture themselves differently from those without NSLBP, changes in movement and posture infrequently relate to improvements in NSLBP when analysed at a group-level. Additionally, little is known about how movement or posture change when clinical outcome improves.

Methods: Within-person relationships were investigated using a replicated, repeated measures, single-case design in 12 people with persistent, disabling NSLBP. Individually relevant movement and posture were captured using wearable sensors on up to 20 occasions over a 22-week period (5-week baseline, 12-week physiotherapy-led intervention, 5-week follow-up), while pain and activity limitation were collected concomitantly. A series of cross-correlation analyses estimated the presence, strength, and direction of relationships.

Results: Many participants ($n = 10/12$) had strong (e.g. $r = 0.91$, $p = <0.001$) relationships between changes in movement or posture and changes in pain and activity limitation, while some showed no strong association. Where relationships were observed, clinical improvement predominantly (93% or 57/61 relationships) related to increased spinal movement range and velocity during forward bending and lifting, reduced lumbar muscle EMG activity at maximum voluntary flexion, and increased posterior-pelvic-tilt during sitting and standing.

Conclusion: Within-person changes to individually relevant movement and posture appear to often relate to clinical outcome, but not always. When changes were related, movement and posture appear to return towards being 'less protective', however causal directions remain unknown. Important activities, movements, and postural parameters varied across the participants, highlighting the potential importance of individualized management.

Significance: Changes to individually relevant movement and posture appear to often relate to clinical outcome, but not always. Patient-specific activities, and movement or postural parameters that related to improved pain and activity limitation, varied across the 12 participants, highlighting the potential importance of individualised

Eur J Pain. 2020;24:1831–1849. wileyonlinelibrary.com/journal/ejp

5.2 Introduction

management. Where clinical improvements were related to changes in movement or posture, participants consistently returned towards being 'less protective' (increased range and speed of movement, increased posterior-pelvic-tilt during sitting and standing). Mechanisms and generalizability remain unclear.

1 | INTRODUCTION

Low back pain (LBP) is common and costly (Deloitte, 2019; Hoy et al., 2014; Institute of Medicine, 2011). Approximately 90% of individuals with LBP are classified as having non-specific LBP because no specific patho-anatomical cause can be identified (Koes et al., 2010; Maher, Underwood, & Buchbinder, 2017). There is evidence that numerous, biopsychosocial factors contribute to NSLBP (Hartvigsen et al., 2018). Movement and posture are commonly believed by patients, clinicians and researchers to relate to NSLBP (Lin et al., 2013; Marras et al., 1995; Mottram & Blandford, 2019; O'Sullivan, 2005). A strong emphasis is placed on the assessment of movement and posture in people with NSLBP (Been & Kalichman, 2014; van Dijk et al., 2020) and interventions often aim to change movement or posture with the belief that this will improve pain or activity limitation (Karayannis, Jull, & Hodges, 2016).

Cross-sectional data demonstrates that, on average, people with back pain move their back slower, with less range of motion (ROM), and increased activity of their lumbar extensor muscles at maximum voluntary flexion (absence of the flexion-relaxation phenomenon; Watson, Booker, Main, & Chen, 1997) compared to people without back pain (Geisser et al., 2005; Gizzi, Röhrle, Petzke, & Falla, 2019; Laird, Gilbert, Kent, & Keating, 2014; Nolan, O'Sullivan, Newton, Singh, & Smith Benjamin, 2019). For posture, however, there does not appear to be a clear difference in standing lumbar lordosis angle or pelvic tilt angle between people with and without LBP (Laird et al., 2014) and differences in lumbar sitting posture or muscle activity were only found between people with and without LBP when types of LBP were subgrouped (Astfalck et al., 2010; Dankaerts, O'Sullivan, Burnett, & Straker, 2006). This may indicate that different movement and postural parameters are significant for different people, highlighting the potential importance of analysing individually relevant factors.

Despite some evidence that people with LBP move and may posture themselves differently, three systematic reviews reported that changes in these kinematic and muscle activity parameters infrequently accompany changes in pain or activity limitation (Laird, Kent, & Keating, 2012; Steiger, Wirth, de Bruin, & Mannion, 2012; Wernli et al., 2020). This may be because improvements in LBP are less related to changes in movement or posture than currently believed, or it may represent limitations in the data and analyses used in the included studies of those reviews.

The first limitation is that analysing the relationship between change in two variables (such as movement and pain) only at a grouplevel is imprecise because different people may have improved in different variables (for example, the people whose movement improved may not be the same people whose pain improved; Wernli et al., 2020). This highlights the need to analyse within-person relationships.

The second limitation is that investigating the same movement parameter across the whole group may dilute the strength of any relationship if different people have different pain-provoking movements and postures. It could be that the strength of those relationships may only be identified when *individually relevant* movements and postures are measured and analysed (Lillie et al., 2011; Tate, Perdices, Rosenkoetter, Shadish, et al., 2016; Wernli et al., 2020). Repeating measures over time also provides greater insight into how two variables relate (Tate, Perdices, Rosenkoetter, Shadish, et al., 2016). To date there is a paucity of literature investigating this phenomenon. This may be due to the historically complex and costly methods available to measure movements and postures (e.g. motion analysis laboratory). However, advances in wearable sensor accuracy to repeatedly measure individually relevant movements and postures in efficient and ecologically valid ways facilitate the investigation of this relationship (Artus, van der Windt, Jordan, & Hay, 2010; Dobkin, 2013; Mjosund et al., 2017).

Therefore, our aim was to investigate, in a replicated single-case study of 12 people with persistent disabling NSLBP, the within-person relationships between:

1. change in movement or posture, and change in pain
2. change in movement or posture, and change in activity limitation

2 | MATERIALS AND METHODS

2.1 | Design

An A-B-A', replicated single-case study of 12 individuals with persistent, disabling NSLBP. Movement or posture, pain, and activity limitation were measured on up to 20 occasions over 22 weeks.

5.3 Methods

Phase A consisted of weekly measures across a 5-week baseline phase during which participants received no intervention. The baseline phase was designed to act as a comparator to determine change within each person (Tate et al., 2013). *Phase B* was a 12-week intervention phase where participants received up to 10 sessions of a physiotherapist-led, individualized, behavioural intervention called Cognitive Functional Therapy (CFT) (O'Sullivan et al., 2018) and had the same measures as during Phase A collected on up to 10 occasions. Intervention onset was determined a priori to occur after the 5-week baseline phase. As the effect of behavioural interventions are expected to carry over after the intervention has ceased (a nonwithdrawable intervention), the subsequent *Phase A'* was used as a follow-up monitoring period during which participants received no intervention. This phase consisted of the same weekly measures over 5 weeks. As this study focussed on the relationship between two variables (*not* on optimizing internal validity to observe a treatment effect), no randomization was utilized (such as randomization of treatment commencement).

2.2 | Participants

Participants were recruited through word of mouth, social media, community advertising, and referrals from primary care practitioners. *Inclusion criteria were*: adults aged 18 years or older with a primary complaint of nonspecific LBP (between T12 and the gluteal folds) that was persistent (>12-weeks duration), disabling (≥5 points on the 23-item Roland Morris Disability Questionnaire [RMDQ]; Patrick et al., 1995), and nontrivial (a mean of ≥3/10 across three 11-point Numeric Rating Scales identifying current, average, and worst pain over the last week; Manniche et al., 1994). Participants also had to report that their pain was provoked by movements or postures. *Exclusion criteria were*: dominant leg pain, a diagnosis of LBP related to specific pathologies (infection, cancer, inflammatory disorders, fracture, radicular pain with neurological deficit), pregnancy, an inability to adequately speak or understand English, a Body Mass Index >30 kg/m^2 (to limit validity concerns about body surface-based movement and postural measures in overweight or obese individuals), nondisabling LBP (mean baseline Patient Specific Functional Scale score <3/10 for two consecutive weeks), and a planned leave of absence greater than two consecutive weeks throughout the 22-week study period (due to the intensive and frequent measurements required for analysis).

2.3 | Context

The study was conducted within a primary care musculoskeletal physiotherapy practice in Perth, Western Australia. On occasion, measurements of movements and postures occurred at the participants home. Data were collected in two waves of six people between January and December 2018.

Each participant provided written informed consent prior to the start of the study. The study was approved by the Human Research Ethics Committee at Curtin University – approval number HRE2017-0706.

2.4 | Measures and equipment

2.4.1 | Repeated measures of pain intensity

Current pain, average pain, and worst pain over the last week were rated on an 11-point numerical rating scale collected via electronic questionnaire up to 20 times. The mean of these three pain ratings was used as a composite estimate of pain intensity (Manniche et al., 1994).

2.4.2 | Repeated measures of activity limitation

The Patient Specific Functional Scale (PSFS) (Westaway, Stratford, & Binkley, 1998) was collected via electronic questionnaire up to 20 times. Participants nominated three activities when asked to identify the *three most important activities of daily life that you are unable/find difficult to do over the last week as a result of your back problem.* They rated how well they were able to perform the activity compared to before their injury or problem on an 11-point numerical rating scale anchored by '0 = able' and '10 = unable'. The three PSFS activities were corroborated with the researcher collecting the movement and postural data during the first baseline session and if any further activities not listed were identified, they were subsequently also collected. The PSFS score reflecting the most disabling movement and (if applicable) posture was used for analysis.

A 23-item RMDQ (Patrick et al., 1995) was also collected at baseline.

2.4.3 | Repeated measures of movement and posture

The heterogeneity of LBP means that participants may have varying key activity limitations, and different movement, postural, and other biopsychosocial factors that contribute to their pain (Hartvigsen et al., 2018; Maher et al., 2017). Therefore, the specific movements and postures nominated by the participant in the PSFS were measured up to 20 times, with the most disabling (identified by the highest mean PSFS score across the baseline phase) movement and

Figure 5-2 ViMove v5 wireless wearable sensor. Single-case series

(if applicable) posture used for analysis. For the movement and postural tasks, the environment was kept consistent (including surface, object lifted, seat height and the absence of a back support during sitting) and instructions were given to perform the task in a natural, self-selected way (including self-selected speed).

Sagittal plane kinematics were collected using two wireless wearable movement sensors (inertial measurement units or IMUs) sampling at 20 Hz and lumbar muscle activity was collected using two wearable surface electromyographic (EMG) sensors sampling at 300 Hz (v5 ViMove hardware and software, DorsaVi, Melbourne, Australia) (Figure 1). The clinical sensor system facilitated the frequent field-based measures required in this design and has demonstrated clinically acceptable agreement compared with the Vicon motion capture system, the industry reference standard (Mjosund et al., 2017). Using a standardised procedure, the IMUs were placed over T12 and S2, and the EMG sensors were applied two centimetres either side of L3 following light abrasion and cleaning of the skin. The IMUs were calibrated to vertical and the EMG was normalized to the mean of three sub-maximal isometric contractions performed at the start of each data collection session. The normalization task involved lying prone, bending the knees to 90°, then lifting the knees approximately five centimetres high for five seconds

FIGURE 1 The ViMove v5 wireless wearable sensor system to collect kinematics and muscle activity

(Dankaerts, O'Sullivan, Burnett, Straker, & Danneels, 2004). Further information about the sensor specifications and processing is detailed in Methods S1.

The most representative biomechanical parameters for each movement and posture were determined a priori (detailed in Methods S1). For bending, T12 peak ROM and mean flexion velocity (VEL), as well as the normalized EMG activity during the middle two seconds of a 5-s hold at peak voluntary flexion during forward bending (representing the flexion relaxation phenomenon; Watson et al., 1997) were output. If a participant had a normal flexion relaxation phenomenon (EMG silence at full flexion), they were still included in the analysis. The mean of three trials was analysed unless trials were excluded due to sensor error.

For lifting, the T12 angle at the start of the lifting phase and the mean lifting velocity were output, with the mean of three trials analysed. The parameters for the movements are presented visually in Figure 2.

For postures, the mean S2 angle over 15 s of self-selected unsupported sitting and standing, and the mean T12 angle over 15 s of sustained extension were output and analysed.

2.4.4 | Procedural fidelity and blinding

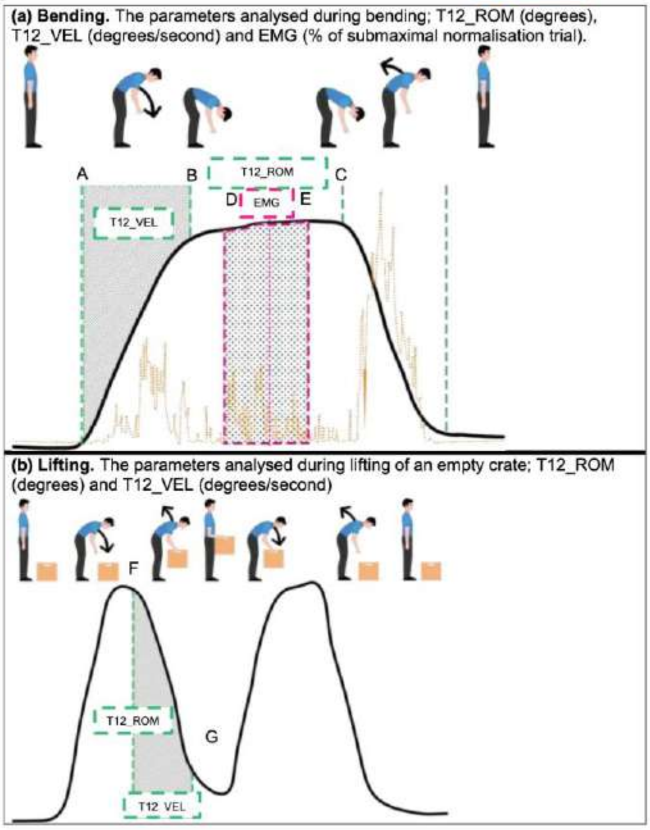
To ensure procedural fidelity, the researcher collecting the movement and postural data was not involved in the delivery of the intervention and participants were blind to the wearable sensor data. Data collection procedures were kept consistent within individuals and collected by the same person using the same procedures. The researcher assessing movement and postures was blind to all measures of pain and activity limitation, except during the last baseline session where the researcher conducted a qualitative interview unrelated to this manuscript investigating the participants perception of change (so 95% of measurement sessions were blinded).

2.5 | Analysis

A series of cross-correlation analyses were performed using Simulation Modelling Analysis (SMA Version 8.3.3, http://clinicalresearcher.org; Borckardt, 2008) to statistically estimate the significance, strength, and direction of relationships between each movement or postural parameter, and pain and activity limitation. A cross-correlation analyses (using SMA) correlates two streams of time-series data within the same person. SMA is a bootstrapping method effective at handling short time series data-streams (<30 measures), whilst both adjusting for autocorrelation and reducing the risk of Type I and II errors (Borckardt, 2008). SMA is a nonparametric approach, where the empirical p-value was equal to the proportion of times two data streams of the same size and

Figure 5-3 Kinematic and EMG outputs. Single-case series

FIGURE 2 The outputs analysed during the (a) bending and (b) lifting movements[a]. Solid black line (___): T12_ROM; Orange line (......): EMG; A: flexion start; B: flexion end; C: re-extension start; D: EMG start; E: EMG end; F: lifting start; G: lifting end; T12_ROM: T12 range of motion (degrees); T12_VEL: T12 angular velocity (degrees per second); EMG: normalized lumbar muscle electromyography. [a]Angular velocity exceeding ±7 degrees/second identified movement commencement, while angular velocity under ±7 degrees/second identified movement cessation (Laird, Keating, Ussing, Li, & Kent, 2019)



autocorrelation are associated in 1,000 bootstrap samples at the observed value of r or greater. The strength of the correlation coefficients was assessed as nonsignificant, small ($r = 0.10$ to <0.30), medium ($r = 0.30$ to <0.50) and large ($r = \geq 0.50$) (Cohen, 1988). As per previous research utilizing cross-correlation analysis to examine temporal associations between variables in people with persistent, disabling LBP undergoing CFT intervention (Caneiro, Smith, Linton, Moseley, & O'Sullivan, 2019) correlations between movement or posture, and pain and activity limitation were estimated over a series of five time-lags from −2 to +2 weeks. This allowed consideration of the potential for change in movement or posture to either precede (positive lag), follow (negative lag), or occur concurrently (zero lag) with changes in pain or activity limitation over a 4-week period. The strongest correlation of the five lag estimates was reported, with all correlations presented in Table S2. As the constructs of interest had the potential to change during the baseline and follow-up phase, the analysis used all available data points during the 22-week study period.

In addition, a test for change in pain and activity limitation from the baseline to intervention was performed using a series of simulation models (5,000 simulations) of the correlation between the phase vector (baseline phase compared to combined intervention and follow-up phase) and outcome (repeated measures of pain or activity limitation), that also provided its p-value. Although not directly related to the study aims, this test was performed to enable a summary of whether or not pain and activity limitation improved for each participant. A threshold of significance of $p = <.1$ was used for this analysis due to the exploratory nature of classifying whether or not a change had occurred.

Results were reported in varying levels of granularity, from individual participants and individual movements at various lags, right up to a single descriptive summary measure where all of the analysed relationships about changes to movement or posture were combined.

2.6 | Intervention

The physiotherapists utilized Cognitive Functional Therapy (CFT), an individualized, behavioural approach for the management of LBP, after serious and specific pathology has been

5.4 Results

excluded (O'Sullivan et al., 2018). CFT is aligned to contemporary guidelines, providing individualized self-management that targets both psychological and physical barriers for recovery of people with disabling NSLBP (Maher et al., 2017). CFT targets both individually relevant movements and postures identified as painful and disabling for the person, as well as the cognitive and emotional factors that underpin them (O'Sullivan et al., 2018). It has shown promising results in the reduction of pain and activity limitation (Caneiro et al., 2019; O'Keeffe, O'Sullivan, Purtill, Bargary, & O'Sullivan, 2019; O'Sullivan, Dankaerts, O'Sullivan, & O'Sullivan, 2015; Vibe Fersum, O'Sullivan, Skouen, Smith, & Kvåle, 2013; Vibe Fersum, Smith, Kvale, Skouen, & O'Sullivan, 2019), and therefore provided an opportunity to create change, facilitating the investigation of relationships between movement, posture, pain, and activity limitation.

Up to 10 sessions of CFT were provided over the 12-week intervention phase depending on the clinical course. The initial session was 60 min, while subsequent sessions were 30–45 min. Four specially trained physiotherapists who had undergone competency assessment by the developer of CFT (POS) provided the treatment. POS was present for the initial intervention session and monitored subsequent sessions through regular contact with the treating physiotherapists to ensure treatment fidelity.

2.7 | Registration

The study was registered with the Australian and New Zealand Clinical Trials Registry – ANZCTR study registration number: ACTRN12619001133123. There were no deviations from the protocol but updates to the selection criteria (excluding those with nondisabling LBP (two consecutive weeks with a mean PSFS < 3/10) and excluding those with a planned leave of absence greater than two consecutive weeks) were made. This occurred during the recruitment and baseline phase of the first six participants and was detailed in the trial registration.

The reporting of this study complies with the Single-Case Reporting guideline In Behavioural interventions (SCRIBE) 2016 (Tate, Perdices, Rosenkoetter, Shadish, et al., 2016).

2.8 | Procedural changes

A major benefit of replicated single-case designs are their flexibility (Tate, Perdices, Rosenkoetter, McDonald, et al., 2016) and, as this was a pragmatic study involving significant participant burden, a degree of flexibility was allowed to minimise this burden for individuals. If a participant was unwell, away or unable to make a data collection session, every attempt was made to collect the measures at another time or in their home. Only movement and postural measures with concomitant questionnaire measures were analysed. Movement and postural measures for P01, P02, P04 and P05 were initially captured with novel, research grade IMUs and surface EMG wearable sensors. These were substituted for a more reliable version because fidelity checking of the data led to the detection of a hardware error after the second or third baseline measure (depending on the stage of the participant). This resulted in a shorter baseline period for those participants but did not affect the statistical analysis (Borckardt, 2008).

2.9 | Dissemination materials

The study was summarized into an infographic (Figure 3) and a video abstract was produced to facilitate dissemination and knowledge translation.

3 | RESULTS

3.1 | Participant characteristics

Twelve (six male and six female) individuals participated, aged from 22 to 76 years old - see Table 1 for the brief demographic characteristics of each participant. More detailed demographic characteristics and clinical features for each participant can be found in Table S1.

Duration of LBP ranged from 11 months to 17 years with many having had to take time off work due to their back pain. Participants had typically received many previous types of treatments and utilised multiple healthcare services without substantial benefit. Nine (75%) had other health co-morbidities and nine (75%) had family members with low back pain. The most commonly nominated PSFS movements and postures were forward bending, followed by sitting, walking, lifting and standing.

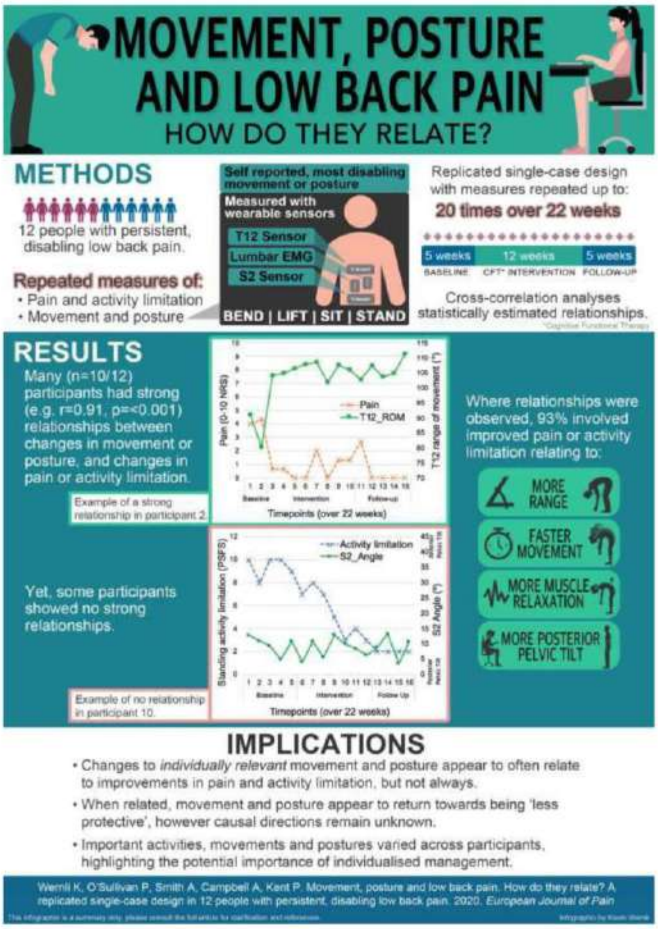
All participants completed all three phases of the study, including the 12-week intervention. The median number of intervention sessions was nine (range 6–10). There were no adverse events. Overall, 222 of the 240 of the scheduled measures (92.5%) were collected and no participant had a lapse in serial measures greater than 2 weeks. Twenty-two of the 816 (2.7%) movement and postural trials collected over the 22-week study period were excluded due to IMU error (e.g. sync error, sensor drift or clothing interference).

3.2 | Outcomes

3.2.1 | Change in pain and activity limitation

Nine of 12 (75%) participants (P02, P03, P06-P12) showed significant improvement in pain when comparing their baseline

FIGURE 3 An infographic summarizing the study



phase to their combined intervention and follow-up phases using simulation modelling analysis (Borckardt, 2008). Eleven of 12 (92%) participants (P02-P12) showed a significant improvement to their movement-based activity limitation (e.g. forward bending), while seven of eight (88%) participants (P4, P6-P11) showed a significant improvement to their posture-based activity limitation (e.g. sitting). The detailed results, as well as figures showing the plots of pain, movement-related activity limitation and posture-related activity limitation for each participant over the study period are presented in Results S1.

3.2.2 | Relationships

The strongest correlations between a lag of −2 and +2 weeks for each movement or postural parameter, and the proportion of nonsignificant, small ($r = 0.10$ to <0.30), medium ($r = 0.30$ to <0.50), and large ($r = \geq 0.50$) correlation relationships (Cohen, 1988) are presented in Tables 2 and 3 with results for all time-lags displayed in Table S2. Ten of 12 (83%) participants (P02-P09, P11, P12) showed at least one large ($r = \geq 0.50$) and significant relationship between changes in a movement or posture and changes in pain or activity limitation, while P01 and P10 did not show any large ($r = \geq 0.50$) and significant relationships.

All 12 participants nominated movement-related activity limitations in their PSFS. Forward bending was the most disabling (highest mean baseline PSFS score) movement for 11 participants (P01-P05, P07-P012), while one participant's most disabling movement was lifting (P06). Changes in movement parameters were often strongly related to changes in pain and activity limitation (P02-P09, P11, P12), with many participants showing significant relationships with all

Table 5.1 Baseline demographics. Single-case series

TABLE 1 Brief overview of participant baseline demographics, the most disabling patient specific functional activity (movement and if available, posture) and the number of assessment sessions available for analysis

Participant	Key baseline demographics: Age (years)	Gender	Duration of LBP	RMDQ (0–23)	Most disabling movement and (if applicable) posture nominated in PSFS	Number of assessment sessions available for analysis[a]
P01	76	Female	Intermittent for ~15 years, intensified over last year	15	Forward bending[b]	15
P02	38	Male	5 years and 3 months	17	Forward bending	15
P03	40	Female	1 year 8 months	18	Forward bending	19[c]
P04	33	Male	9 years	16	Forward bending Sitting	18 (16 for postures)
P05	68	Male	5–6 years	12	Forward bending Sitting	18
P06	28	Female	11 months	19	Lifting Sitting	18[c]
P07	26	Female	7 years	22	Forward bending Sitting	20
P08	50	Female	5 years	18	Forward bending Standing	19 (17 for postures)
P09	43	Male	17 years	10	Forward bending Extension (sustained standing and looking up ladder)	20
P10	22	Female	6 years	12	Forward bending Standing	20 (16 for postures)
P11	26	Male	6 years	19	Forward bending[d] Standing	19 (18 for postures)
P12	56	Male	3 years	18	Forward bending	18

Abbreviations: LBP, Low back pain; PSFS, Patient Specific Functional Scale; RMDQ, 23-Item Roland Morris Disability Questionnaire.

[a]Measures that did not have corresponding movement and postural (due to device hardware failure), or pain and activity limitation measures (due to incomplete or delayed questionnaire responses) were excluded from the analysis.

[b]No normalised EMG data was available for P01 as she requested to be exempt from the normalisation procedure.

[c]P03 and P06 had five measures captured over a three-week baseline phase because they were substitutes for two participants who were excluded because their PSFS score during the first two weeks did not reflect disabling LBP.

[d]The EMG data for P11 was excluded due to validity concerns related to spinal fusion surgery causing scar tissue underlying the EMG sensors.

Table 5.2 Movement cross-correlations. Single-case series

TABLE 2 The strongest cross-correlations[a] between *movement*, pain and activity limitation for each participant between time-lag[b] −2 and +2 weeks

Participant, PSFS activity and movement parameter	Strongest cross-correlation between time-lag −2 and +2 weeks: Pain (Tri.NRS)	Activity limitation (PSFS)	Proportion showing relationship: NonSignificant	Small (r = 0.10–<0.30)*	Medium (r = 0.30–<0.50)*	Large (r = ≥0.50)*	Total significant relationships
P01							
Forward bending[c]							
T12_ROM	**r=−0.48 p = .034* (LAG:0)**	r=+0.22 p = .212 (LAG:−2)	3		1		1/4 (25%)
T12_VEL	r=−0.41 p = .054 (LAG:+2)	r=+0.33 p = .099 (LAG:0)					
P02							
Forward bending							
T12_ROM	**r=−0.78 p = .001* (LAG:0)**	**r=−0.78 p = .000* (LAG:0)**				6	6/6 (100%)
T12_VEL	**r=−0.68 p = .005* (LAG:0)**	**r=−0.80 p = .000* (LAG:0)**					
EMG	**r=+0.77 p = .002* (LAG:0)**	**r=+0.68 p = .000* (LAG:0)**					
P03							
Forward bending							
T12_ROM	**r=−0.71 p = .004* (LAG:0)**	**r=−0.77 p = .002* (LAG:0)**	2			4	4/6 (67%)
T12_VEL	**r=−0.53 p = .017* (LAG:0)**	**r=−0.65 p = .003* (LAG:0)**					
EMG	r=+0.34 p = .073 (LAG:0)	r=−0.27 p = .117 (LAG:−2)					
P04							
Forward bending							
T12_ROM	**r=−0.59 p = .016* (LAG:+1)**	**r=−0.70 p = .003* (LAG:+1)**				6	6/6 (100%)
T12_VEL	**r=−0.58 p = .031* (LAG:0)**	**r=−0.81 p = .002* (LAG:0)**					
EMG	**r=+0.68 p = .004* (LAG:+1)**	**r=+0.88 p = .000* (LAG:+1)**					
P05							
Forward bending							
T12_ROM	**r=−0.76 p = .003* (LAG:0)**	**r=−0.67 p = .006* (LAG:0)**	1		3	2	5/6 (83%)
T12_VEL	**r=−0.39 p = .013* (LAG:−2)**	**r=−0.39 p = .022* (LAG:−2)**					
EMG	**r=+0.35 p = .041* (LAG:+2)**	r=+0.33 p = .069 (LAG:0)					
P06							
Lifting							

(Continues)

TABLE 2 (Continued)

Participant, PSFS activity and movement parameter	Strongest cross-correlation between time-lag −2 and +2 weeks: Pain (Tri.NRS)	Strongest cross-correlation between time-lag −2 and +2 weeks: Activity limitation (PSFS)	Proportion showing relationship: NonSignificant	Small (r = 0.10–<0.30)*	Medium (r = 0.30–<0.50)*	Large (r = ≥0.50)*	Total significant relationships
T12_ROM	**r=−0.69 p = .005* (LAG:+2)**	**r=−0.72 p = .005* (LAG:+2)**				4	4/4 (100%)
T12_VEL	**r=−0.72 p = .008* (LAG:0)**	**r=−0.79 p = .001* (LAG:0)**					
P07							
Forward bending							
T12_ROM	**r=+0.55 p = .004* (LAG:0)**	**r=+0.52 p = .012* (LAG:0)**	3		1	2	3/6 (50%)
T12_VEL	**r=−0.41 p = .036* (LAG:−1)**	r=−0.44 p = .050 (LAG:0)					
EMG	r=−0.24 p = .120 (LAG:0)	r=−0.18 p = .179 (LAG:0)					
P08							
Forward bending							
T12_ROM	**r=−0.69 p = .006* (LAG:+2)**	**r=−0.65 p = .015* (LAG:+2)**				6	6/6 (100%)
T12_VEL	**r=−0.86 p = .003* (LAG:0)**	**r=−0.81 p = .005* (LAG:0)**					
EMG	**r=+0.52 p = .015* (LAG:+1)**	**r=+0.53 p = .013* (LAG:+1)**					
P09							
Forward bending							
T12_ROM	**r=−0.64 p = .016* (LAG:−2)**	**r=−0.69 p = .006* (LAG:−2)**				6	6/6 (100%)
T12_VEL	**r=−0.81 p = .000* (LAG:+1)**	**r=−0.80 p = .000* (LAG:+2)**					
EMG	**r=+0.91 p = .000* (LAG:0)**	**r=+0.82 p = .000* (LAG:−1)**					
P10							
Forward bending							
T12_ROM	r=+0.41 p = .060 (LAG:0)	r=+0.37 p = .069 (LAG:0)	4		2		2/6 (33%)
T12_VEL	**r=−0.49 p = .015* (LAG:+2)**	**r=−0.44 p = .032* (LAG:+2)**					
EMG	r=−0.32 p = .065 (LAG:+2)	r=−0.26 p = .131 (LAG:−1)					
P11							
Forward bending[c]							
T12_ROM	**r=−0.86 p = .000* (LAG:0)**	**r=−0.91 p = .000* (LAG:0)**				4	4/4 (100%)
T12_VEL	**r=−0.88 p = .000* (LAG:0)**	**r=−0.87 p = .001* (LAG:0)**					
P12							
Forward bending							

(Continues)

TABLE 2 (Continued)

Participant, PSFS activity and movement parameter	Strongest cross-correlation between time-lag −2 and +2 weeks: Pain (Tri.NRS)	Activity limitation (PSFS)	Proportion showing relationship: NonSignificant	Small (r = 0.10–<0.30)*	Medium (r = 0.30–<0.50)*	Large (r = ≥0.50)*	Total significant relationships
T12_ROM	**r=−0.57 p = .011* (LAG:+2)**	**r=−0.55 p = .041* (LAG:0)**				6	6/6 (100%)
T12_VEL	**r=−0.62 p = .013* (LAG:0)**	**r=−0.65 p = .004* (LAG:0)**					
EMG	**r=+0.77 p = .000* (LAG:0)**	**r=+0.60 p = .002* (LAG:+1)**					

Abbreviations: EMG, Electromyographic activity of the lumbar muscles normalised to an isometric, sub-maximal contraction (%Submax); PSFS, Patient Specific Functional Scale (0–10 scale); S2_Angle, Mean angle of the upper sacrum (S2) sensor during static posture (degrees); T12_ROM, Peak range of movement of the thoracolumbar (T12) sensor (degrees); T12_VEL, Mean velocity of the thoracolumbar (T12) sensor (degrees/sec); Tri.NRS, Mean numerical rating of current pain, average and worst pain over last week (0–10 scale).

[a]Cross-correlation analyses performed using Simulation Modelling Analysis.

[b]A lag of zero indicates the two variables likely occurred together, a positive lag indicates that a change in movement or posture likely *preceded* a change in pain or activity limitation, and a negative lag indicates that a change in movement or posture likely *followed* a change in pain or activity limitation.

[c]No normalised EMG data available for analysis. P01 requested to be exempt from the normalisation task and P11 had significant scar tissue underlying the sEMG sensors following lumbar fusion surgery resulting in validity concerns of the EMG data.

*p = <0.05.

parameters (ROM, speed and EMG activity). However, some participants only had significant relationships with select movement parameters or with just pain or activity limitation (e.g. P01 showed significant relationships with changes in range and pain, but not velocity and pain, while P10 showed significant relationships with changes in velocity but not range for both pain and activity limitation). Changes in lumbar EMG activity were also often but not always related to changes in pain or activity limitation among the participants, with relationships identified in six of nine participants (P02, P04, P05, P08, P09, and P11).

Of the eight participants that nominated a posture-related activity limitation in their PSFS (P04-P11), sitting was the most disabling in four (P04-P07), standing was the most disabling in three (P08, P10, P11), and sustained extension was the most disabling in one (P09). Similar to relationships for movements, relationships between changes in posture and changes in pain and activity limitation were found in some participants (P04, P06-P08 and P11), but not all.

Figure 4 displays raw data plots for exemplar cases that did and did not show relationships while a summary of the relationships, their direction and strength for each movement and posture is provided in Table 4.

3.2.3 | Summary of relationships and their directionality

Of the 82 investigations of association between changes in movement or posture, and changes in pain and activity limitation, a relationship was identified 61 (74%) times. Of these 61 relationships, increased ROM and velocity during bending and lifting, less muscle activity during end of range voluntary flexion, and increased posterior-pelvic-tilt during sitting and standing were related to improved pain and activity limitation 57 (93%) times.

Of the remaining 21 associations investigated where a relationship was not identified, 16 (20% of all associations investigated) involved improvements in pain or activity limitation in the absence of a relationship with movement or posture, and 5 (6%) involved no change to pain or activity limitation.

3.2.4 | Time-lag

Thirty-three of 61 (54%) of the strongest significant relationships occurred at a time-lag of zero, 19 of 61 (31%) at a positive time-lag, and 9 of 61 (15%) at a negative time-lag. This indicates that when analysed at a frequency of almost weekly, relationships between movements or postures, and pain and activity limitation were largest when analysed contemporaneously, suggesting that changes usually occurred together.

Table 5.3 Posture cross-correlations. Single-case series

TABLE 3 The strongest cross-correlations[a] between the most disabling *posture*, pain and activity limitation for each participant between time-lag[b] −2 and +2 weeks

Participant, PSFS activity and postural parameter	Strongest cross-correlation between time-lag −2 and +2 weeks		Proportion showing relationship				
	Pain (Tri.NRS)	Activity limitation (PSFS)	NonSignificant	Small (r = 0.10—<0.30*)	Medium (r = 0.30–<0.50)*	Large (r = ≥0.50)*	Total significant relationships
P04							
Sitting[c]							
S2_Angle	r=+0.37 p = .105 (LAG:+1)	**r=+0.60 p = .016* (LAG:0)**	1			1	1/2 (50%)
P05							
Sitting							
S2_Angle	r=+0.18 p = .198 (LAG:−2)	r=+0.26 p = .108 (LAG:−2)	0				0/2 (0%)
P06							
Sitting							
S2_Angle	**r=+0.63 p = .003* (LAG:+2)**	**r=+0.58 p = .017* (LAG:+2)**				2	2/2 (100%)
P07							
Sitting							
S2_Angle	**r=−0.59 p = .004* (LAG:−1)**	**r=−0.64 p = .002* (LAG:−2)**				2	2/2 (100%)
P08							
Standing[c]							
S2_Angle	r=+30 p = .0.056 (LAG:0)	**r=+0.37 p = .035 (LAG:0)**	1		1		1/2 (50%)
P09							
Sustained extension							
T12_Angle	r=−0.26 p = .102 (LAG:−1)	r=−0.34 p = .051 (LAG:0)	2				0/2 (0%)
P10							
Standing[c]							
S2_Angle	r=+0.11 p = .304 (LAG:+2)	r=+0.09 p = .324 (LAG:+2)	2				0/2 (0%)
P11							
Standing[c]							
S2_Angle	**r=+0.79 p = .002* (LAG:0)**	**r=+0.79 p = <.001* (LAG:−1)**	0			2	2/2 (100%)

Abbreviations: PSFS, Patient Specific Functional Scale (0–10 scale); S2_Angle, Mean angle of the upper sacrum (S2) sensor during static posture (degrees), T12_Angle, Mean angle of thoracolumbar (T12) sensor during static posture; Tri.NRS, Mean numerical rating of current pain, average and worst pain over last week (0–10 scale).

[a]Cross-correlation analyses performed using Simulation Modelling Analysis.

[b]A lag of zero indicates the two variables likely occurred together, a positive lag indicates that a change in movement or posture likely *preceded* a change in pain or activity limitation, and a negative lag indicates that a change in movement or posture likely *followed* a change in pain or activity limitation.

[c]Outliers removed.

*p = <0.05.

5.5 Discussion

Figure 5-4 Data plots. Single-case series

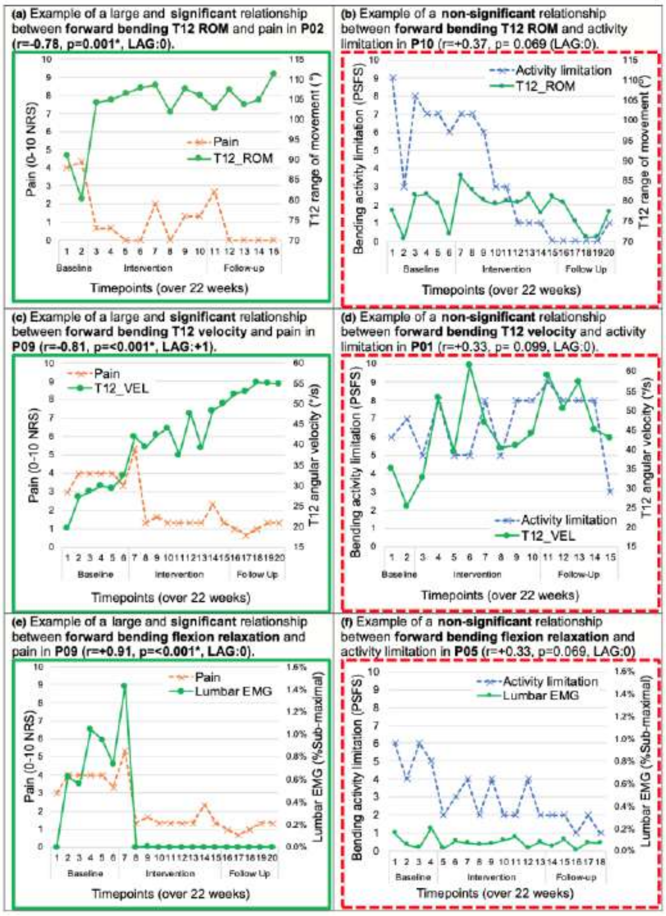


FIGURE 4 Raw data plots exemplifying significant and nonsignificant ($p \leq .05$) relationships between changes in movement or posture, and changes in pain or activity limitation using cross-correlation [a] analysis (between time-lag[b] −2 to +2 weeks).

[a]Cross-correlation analyses performed using Simulation Modelling Analysis.

[b]A lag of zero indicates the two variables likely occurred together, a positive lag indicates that a change in movement or posture likely *preceded* a change in pain or activity limitation, and a negative lag indicates that a change in movement or posture likely *followed* a change in pain or activity limitation.

Solid green border (___): significant relationship; Dashed red border (_ _ _): nonsignificant relationship; TriNRS: Mean numerical rating of current pain, average and worst pain over last week (0–10 scale); PSFS: Patient Specific Functional Scale (0–10 scale); ROM: Range of movement; VEL: T12 angular velocity (degrees per second). $*p < .05$

4 | DISCUSSION

This study investigated the relationship between (a) within-person changes in objectively measured, individually relevant movement or postural parameters, and (b) within-person changes in self-reported pain and activity limitation, in people with persistent, disabling non-specific LBP. Measures were repeated up to 20 times over a 22-week period in each (n = 12) participant to allow the presence and strength of relationships to be statistically estimated over a clinically relevant period. The majority of participants experienced improvements in pain and activity limitation following the onset of the intervention. Most of the time, this improvement was strongly related to changes in movement or posture, but improvements in pain and activity limitation were sometimes unrelated to changes in movement or posture.

That relationships between repeated measures of movement or posture, and pain and activity limitation occurred

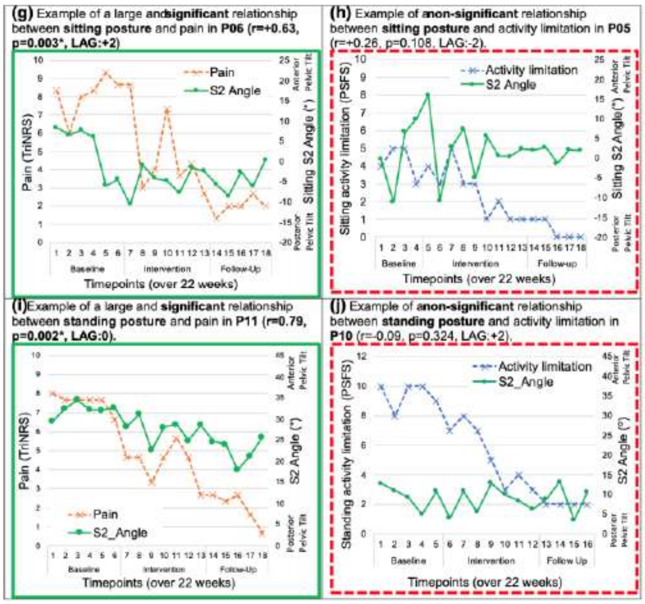


FIGURE 4 Continued

in 74% (61 of 82) of the relationships analysed shows that frequently, changes in movement or posture are related to improved pain and activity limitation when parameters during individually relevant activities are analysed at a within-person level. The frequent identification of a relationship in the current study is in contrast with previous systematic reviews where relationships between changes in movement were infrequently identified (29%, 31% and 'infrequently' among the Steiger et al. (2012), Wernli et al. (2020), and Laird et al. (2012) reviews, respectively. This difference may be due to the ability of the current study to: accommodate individually relevant movements and postures, analyse at a within-person level and the individualized nature of the intervention (O'Sullivan et al., 2018; Wernli et al., 2020).

The within-person design of the current study aligns with contemporary calls for individualized approaches to healthcare (Lillie et al., 2011; O'Brien et al., 2010) and allowed novel insights into relationship frequency, strength and direction. With 10 demonstrations of inter-subject replication of a strong relationship, the current study exceeds the minimum of three replications threshold recommended for the purpose of generality for single-case intervention research (Tate et al., 2013). Although relationships were frequently found, 20% of the time (16 of 82 associations investigated), pain and activity limitation improved despite not being related to changes in movement and posture. It may be that: (a) these particular movement and postural parameters were simply unrelated to that participants presentation, (b) that other, unmeasured factors may have been more related to their improvement, and/or (c) that the participant did not have a movement or postural 'impairment' amenable to change in the first place. A recent cohort study of 266 people (Laird, Keating, & Kent, 2018) that found a sub-group (25%) of people with LBP move 'like people without LBP' is some support for that notion and suggests that the importance of movement and posture is variable amongst people with NSLBP.

The nomination of different PSFS activities and the diverse presence and strength of relationships (both within-person and between people) highlights that different activities, and movement and postural parameters are likely to be important for different people. For example, forward bending was the most disabling pain-provoking task for both P12 and P07, yet P12 showed a significant and strong relationship with EMG, while P07 showed no strong relationship with EMG. This heterogeneity is supported by previous research utilizing a similar design that identified unique patterns of change and variable relationships between proposed mediators and disability across four participants with persistent, disabling NSLBP and high pain-related fear (Caneiro et al., 2019). Notably, Caneiro et al. (2019) related two self-report variables, while the current study related an objectively measured and a self-report variable, reducing the potential bias present when correlating two self-report variables. It appears that people with NSLBP likely have unique

Table 5.4 Summary of cross-correlations. Single-case series

TABLE 4 A summary of the number, direction and strength of cross-correlation[a] relationships observed for each movement and posture

Activity	Parameter	% observed relationship with pain	% observed relationship with activity limitation	% and direction of movement related to improved pain or activity limitation	Range of significant cross-correlation values
Forward bending (most disabling movement in 11 participants - P01-P05, P07-P12)	ROM (peak T12 angle)	91% (10 out of 11 participants)	82% (9 out of 11 participants)	89% increased ROM (17 out of 19 relationships)	$r = -0.48$ to -0.91
	Speed (T12 angular velocity)	91% (10 out of 11 participants)	82% (9 out of 11 participants)	100% increased speed (19 out of 19 relationships)	$r = -0.39$ to -0.87
	Lumbar muscle activity (EMG)	67% (6 out of 9 participants)	56% (5 out of 9 participants)	100% less muscle activity (11 out of 11 relationships)	$r = +0.35$ to $+0.91$
Lifting (most disabling movement in 1 participant – P06)	ROM[b] (T12 Angle)	100% (1 out of 1 participant)	100% (1 out of 1 participant)	100% increased ROM (2 out of 2 relationships)	$r = -0.69$ and -0.72
	Speed (T12 angular velocity)	100% (1 out of 1 participant)	100% (1 out of 1 participant)	100% increased ROM (2 out of 2 relationships)	$r = -0.72$ and -0.79
Sitting (most disabling posture in 4 participants – P04-P07)	S2 Angle	50% (2 out of 4 participants)	75% (3 out of 4 participants)	60% increased posterior-pelvic-tilt (3 out of 5 relationships)	$r = +0.58$ to $+0.64$
Standing (most disabling posture in 3 participants – P08, P10, P11)	S2 Angle	33% (1 out of 3 participants)	66% (2 out of 3 participants)	100% increased posterior-pelvic-tilt (3 out of 3 relationships)	$r = +0.37$ and $+0.79$
Sustained extension (most disabling posture in 1 participant – P09)	T12 Angle	0% (0 out of 1 participant)	0% (0 out of 1 participant)	No relationship identified	No relationship identified

[a] Cross-correlation analyses performed using Simulation Modelling Analysis.

[b] T12 angle at commencement of lifting.

and individually relevant relationships between numerous biopsychosocial factors that influence their presentation and clinical outcome. In heterogenous and complex conditions, rigorous single-case designs with repeated measures provide an opportunity to gather insight into the complex interplay between multiple factors of interest from a within-person, individualized perspective (Caneiro et al., 2019; Kratochwill et al., 2012).

To our knowledge, no other studies have statistically estimated relationships between repeated measures of movement, posture, pain and activity limitation, limiting our ability to make comparisons with other literature. However, a small number of case-reports ($n = 1$) utilizing repeated measures found mixed results when visually estimating an association. Some reported changes to movement that *were* associated with improvements in pain and activity limitation (Jones & Wolf, 1980; Ohtsuki, 2014; Robinson, 2016; Wolf, Nacht, & Kelly, 1982), while some did not (Johansson & Lindberg, 1995; Takasaki & May, 2018). Limitations such as the investigation of only a single participant, no statistical analysis, no assessor blinding, a lack of valid and reliable measurement equipment, selection bias, and selective reporting (due to a lack of registered protocols) may have influenced the findings of those studies. However, when relationships were observed in the those studies, the direction of the movement changes (namely increased spinal ROM and reduced lumbar EMG activity; Jones & Wolf, 1980; Ohtsuki, 2014; Robinson, 2016; Wolf et al., 1982) related to improved pain and activity limitation were concordant with the current findings.

The direction of change in movement and posture in the presence of a relationship was very consistent in this study. That 93% of the time (57 out of 61 associations investigated), increased movement ROM or speed, reductions in lumbar muscle activity at maximum voluntary flexion, or increased posterior-pelvic-tilt during sitting and standing postures were related to improved pain and activity limitation could be interpreted as a potential reduction in 'protective' movement and postural behaviours (O'Sullivan et al., 2018). This finding aligns with a recent systematic review of cohort studies that found increased movement ROM, velocity and flexion-relaxation related to improved pain and activity limitation 93% of the time when relationships between within-person changes in movement and pain or activity limitation were identified in 2,739 people from 27 cohort studies (Wernli et al., 2020). The replication in the current study of those cohort study findings, further support the generality of the findings (Tate et al., 2013). Causal directions, however, (e.g. whether less protective movement and postural patterns resulted in changes to pain or activity limitation, vice versa, or whether changes in both had a separate common cause) remain unknown. Carefully designed experimental and mediational studies, that include psychological factors known to be important for people with disabling NSLBP, such as pain catastrophising, fear and pain self-efficacy, would be required to make causal inferences (Lee et al., 2017; Matheve, De Baets, Bogaerts, & Timmermans, 2019).

Psychological factors (such as pain catastrophising, fear and pain self-efficacy) have been shown to relate more to improved pain or activity limitation than physical parameters such as movement or abdominal muscle function (Mannion, Caporaso, Pulkovski, & Sprott, 2012; Mannion et al., 2001; Nordstoga, Meisingset, Vasseljen, Nilsen, & Unsgaard-Tondel, 2019). Psychological factors have also been shown to influence the embodiment of cautious and protective movement behaviours (Matheve et al., 2019; Olugbade, Bianchi-Berthouze, & Williams, 2019; Osumi et al., 2019) and mediate improvement (Lee et al., 2017; Liew et al., 2020; Mansell, Kamper, & Kent, 2013; Smeets, Vlaeyen, Kester, & Knottnerus, 2006). It may be that threat reduction, following the safe completion of previously painful, feared, or avoided activities perceived as dangerous or damaging, led to clinical improvement, irrespective of whether this was related to changes in movement or posture (Mannion et al., 2012; Steiger et al., 2012). The influence of other unmeasured biopsychosocial and contextual factors on the findings of this study remain unknown.

5 | LIMITATIONS

The study design facilitated the within-person investigation of the relationship between changes in individually relevant movements or postures, and changes in pain and activity limitation. The generality of the study is supported by replication of the findings across participants and alignment of the findings with a recent systematic review of cohort studies (Wernli et al., 2020). Additionally, the demographics of the participants represent the heterogenous populations that clinicians likely encounter. However, only participants reporting pain specifically provoked by movements or postures were included, so it is unknown how broadly the findings relate to all people with low back pain. Furthermore, we only analysed T12 kinematics and lumbar muscle activity for movements and S2 or T12 kinematics for postures to minimize complexity and the number of analyses. Also, the sensors may not provide adequate accuracy to measure small and subtle changes, or lumbar inter-segmental changes which would have required laboratory-based measurements that were not feasible with the current study's field-based design. It is also unknown whether task familiarity or 'the observer effect' influenced our findings. A component of the individualized and integrated biopsychosocial intervention involves the assessment and (if applicable) targeting of meaningful movement and posture, which may mean a relationship was identified more often that it would be using other interventions.

5.6 Conclusion

6 | CONCLUSIONS

Changes to individually relevant movement and posture appear to often relate to clinical outcome, but not always. The heterogeneity of the relationships highlights the importance of identifying individually relevant activities (e.g. by using the PSFS) as well as considering diverse movement and postural parameters in people with NSLBP. When relationships were identified, and pain or activity limitation improved, movement and posture appeared to return towards being 'less protective', however, the influence of other biopsychosocial factors on this change remains unclear.

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CONFLICTS OF INTEREST

The authors certify that they have no affiliations with, financial involvement or conflicts of interest in any organisation or entity with a direct financial interest in the subject matter or materials discussed in the article.

AUTHOR CONTRIBUTIONS

All authors contributed to the conception and design of the study. KW performed data collection and analysis with input from PK, AC, PO and AS. KW prepared the draft of the manuscript. All authors discussed the results and commented on the manuscript.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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5.8 Appendices

5.8.1 Appendix 1: TableS1

Table 5.5 Appendix 1. TableS1. Detailed participant demographics. Single-case series

Participant	Key demographic and clinical features	Patient Specific Functional Limitations
P01	**Age and Gender:** 76-year-old female **Duration of LBP:** Intermittent for ~15 years, intensified over last year **Education level:** School **Occupation:** Retired **Ethnicity:** Dutch **Previous interventions:** Physiotherapy, massage, general practitioner and radiology **Co-morbidities:** 2 cardiac stents, reflux, bronchiectasis **Family history of LBP:** 2 brothers (long-term history, numerous interventions, not recovered). **LBP onset:** Insidious (current episode potentially linked to sit-ups) **Recruitment source:** Social media	**Bending** **Walking** **Vacuuming**
P02	**Age and Gender:** 38-year-old male **Duration of LBP:** 5 years and 3 months **Education level:** School **Occupation:** Real-estate/father **Ethnicity:** Australian **Previous interventions:** Extensive physiotherapy, general practitioner, analgesics, stopping physical activities. **Co-morbidities:** Migraines **Family history of LBP:** Father (20-year history, not recovered, manages) **LBP onset:** Insidious, potentially following sustained squat position **Recruitment source:** Word of mouth	**Bending** **Lifting** (for example the kids) **Sitting** (sitting on floor and getting up)
P03	**Age and Gender:** 40-year-old female **Duration of LBP:** 1 year 8 months **Education level:** School **Occupation:** Mother/cleaner (unable to work at start of study due to LBP) **Ethnicity:** Australian **Previous interventions:** Physiotherapy, massage, chiropractic and general practitioner. **Co-morbidities:** Nil **Family history of LBP:** nil **LBP onset:** Felt pop in back during birth of youngest child (complicated delivery) **Recruitment source:** Social media	**Bending** **Lifting** **Vacuuming**
P04	**Age and Gender:** 33-year-old male **Duration of LBP:** 9 years **Education level:** University **Occupation:** Health Recruiter (~20 days off work due to LBP) **Ethnicity:** Australian **Previous interventions:** Extensive chiropractic, physiotherapy, massage, general practitioner, radiology medication (Ibrufen and paracetamol as required).	**Sitting** **Bending** **Standing**

	Co-morbidities: Nil **Family history of LBP:** Mother (10-year history, not recovered) and sister (1-year history, not recovered). **LBP onset:** Strain playing basketball 9 years ago – got knocked over **Recruitment source:** Social media	
P05	**Age and Gender:** 68-year-old male **Duration of LBP:** 5-6 years **Education level:** School **Occupation:** Retired school teacher **Ethnicity:** Australian **Previous interventions:** Physiotherapy, exercise, massage, general practitioner, radiology, facet-joint injections, epidural and medication (occasional anti-inflammatory) **Co-morbidities:** Mild anxiety **Family history of LBP:** Father (long-term history, back fusion, not recovered) and brother (long-term history, managing, not recovered) **LBP onset: I**nitially felt at golf. Current episode insidious **Recruitment source:** Social media	**Bending** **Sitting (**for example while driving) **Putting on socks**
P06	**Age and Gender:** 28-year-old female **Duration of LBP:** 11 months **Education level:** University **Occupation:** Disability leave, ~6 months off work due to LBP, mother **Ethnicity:** Chinese **Previous interventions:** Physiotherapy, remedial massage, chiropractic, osteopathy, general practitioner, radiology. **Co-morbidities:** High cholesterol **Family history of LBP:** Mother (long term, managing, not recovered) **LBP onset:** Around time of birth of first child. **Recruitment source:** Referral from primary care practitioner	**Lifting** **Sitting** **Doing dishes**
P07	**Age and Gender:** 26-year-old female **Duration of LBP:** 7 years **Education level:** School **Occupation:** Mother **Ethnicity:** Australian **Previous treatments:** Physiotherapy, massage, general practitioner and medication (Pristiq, Tramadol, Codapane Forte) **Co-morbidities:** Depression **Family history of LBP:** Nil **LBP onset:** Around time of birth of first child. **Recruitment source:** Social media	**Bending** **Sitting** **Walking**
P08	**Age and Gender:** 50-year-old female **Duration of LBP:** 5 years **Education level:** University **Occupation:** Counsellor (10 days off work due to LBP) **Ethnicity:** Australian **Previous interventions:** Physiotherapy, massage, general practitioner and medication (Plaquenil, Pristiq, Thyroxine, occasional analgesics and anti-inflammatories) **Co-morbidities:** Lupus, hypothyroidism, depression and anxiety **Family history of LBP:** Sister (long-term, not recovered) and father (long-term, not recovered) **LBP onset:** fall from chair onto tiled floor 5 years ago. **Recruitment source:** Social media	**Standing** **Bending** **Walking**
P09	**Age and Gender:** 43-year-old male **Duration of LBP:** 17 years	**Sitting** (for long periods)

	Education level: School **Occupation:** Own's sign fabrication and installation business (unable to take days off due to nature of occupation) **Ethnicity:** Australian **Previous interventions:** Regular massage and Pilates. Chiropractic, exercise physiologist, osteopath, physiotherapy, cranio-sacral therapy, general practitioner and medication (anti-inflammatories almost daily, now ~once per week). **Co-morbidities:** Nil **Family history of LBP:** Nil **LBP onset:** Insidious **Recruitment source:** Social media	**Lifting** (for example the kids, signs) **Bending** (predominantly in the morning) **Sustained extension** (for example rope access work).
P10	**Age and Gender:** 22-year-old female **Duration of LBP:** 6 years **Education level:** School **Occupation:** unemployed **Ethnicity:** Irish **Previous interventions:** Physiotherapy, general practitioner, radiology, medication (Lyrica, Codeine, Paracetamol) **Co-morbidities:** Depression, anxiety, Post traumatic stress disorder. **Family history of LBP:** Nil **LBP onset:** Insidious around time of stressful life event **Recruitment source:** Referral from primary care practitioner	**Bending** **Standing** **Walking**
P11	**Age and Gender:** 26-year-old male **Duration of LBP:** 6 years **Education level:** School **Occupation:** Unemployed due to LBP (for ~4 years) **Ethnicity:** Australian **Previous interventions:** Spinal surgery (2x Microdiscectomy, 1x spinal Fusion), 2x Corticosteroid injections), physiotherapy, massage, general practitioner and medication (Pristiq, Lyrica, Tramal, Norspan, Palexia) **Co-morbidities:** Nil **Family history of LBP:** Nil **LBP onset:** playing national level hockey. **Recruitment source:** Word of mouth	**Sitting** **Bending** **Standing**
P12	**Age and Gender:** 56-year-old male **Duration of LBP:** 3 years **Education level:** University **Occupation:** Engineer (~30 days off work due to LBP) **Ethnicity:** Australian **Previous interventions:** Physiotherapy, general practitioner, gentle exercise, consulted multiple spinal surgeons and tertiary care practitioners. **Co-morbidities:** Depression, minor bursitis and tinnitus **Family history of LBP:** Sister (long-term, not recovered) and brother (long-term, not recovered) **LBP onset:** Lifting in gym. **Recruitment source:** Social media	**Lifting** **Vacuuming** **Walking** **Bending**

5.8.2 Appendix 2: ResultsS1

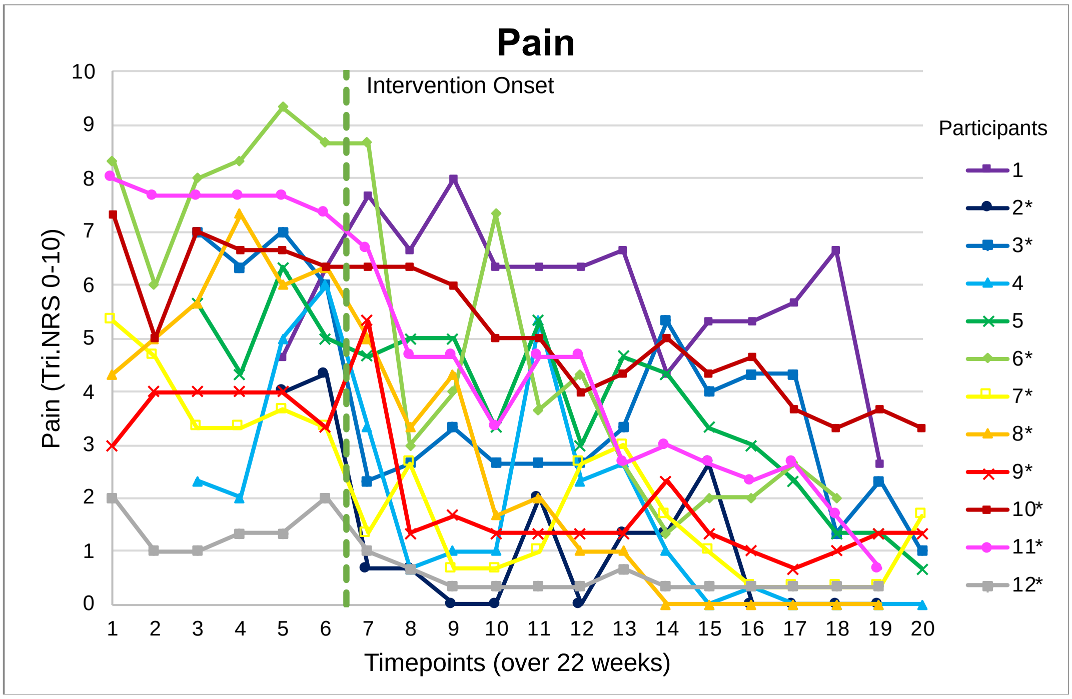
Table 5.6 Appendix 2. ResultsS1. Change in outcome. Single-case series

Change between baseline and intervention (including follow-up) phase for each participant using Simulation Modelling Analysis (SMA). Including figure of pain (Tri.NRS), movement activity limitation (PSFS) and posture activity limitation (PSFS). The r value is the correlation between baseline and intervention (including follow-up) phase, and its p-value.

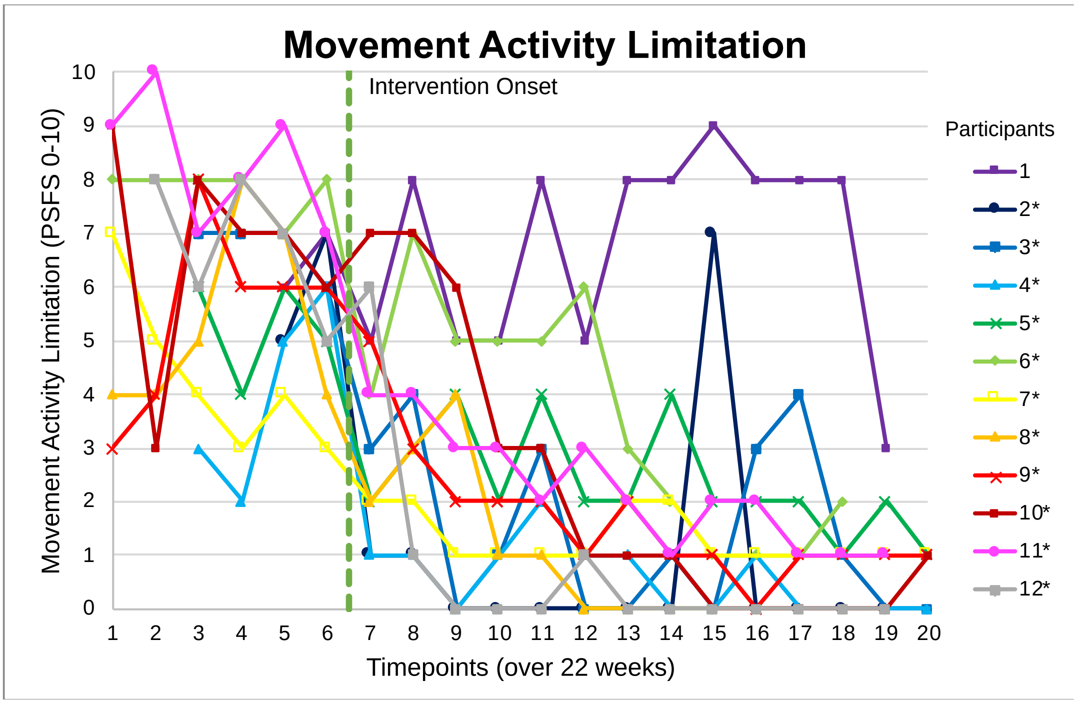
Participant	Did they change?		
	Pain	Movement activity limitation	Posture activity limitation
1	NO (r = +0.131, p = 0.6424)	NO (r = +0.054, p = 0.8512)	
2	YES (r = -0.827, p = 0.006*)	YES (r = -0.715, p = 0.0046*)	
3	YES (r = -0.818, p = 0.0034*)	YES (r = -0.848, p = 0.0014*)	
4	NO (r = -0.560, p = 0.1096)	YES (r = -0.839, p = 0.0010*)	YES (r = -0.796, p = 0.0022*)
5	NO (r = -0.516, p = 0.1494)	YES (r = -0.787, p = 0.0024*)	NO (r = -0.591, p = 0.1408)
6	YES (r = -0.752, p = 0.0398*)	YES (r = -0.775, p = 0.0484*)	YES (r = -0.709, p = 0.0582*)
7	YES (r = -0.815, p = 0.0066*)	YES (r = -0.856, p = 0.0026*)	YES (r = -0.782, p = 0.0106*)
8	YES (r = -0.802, p = 0.0638*)	YES (r = -0.831, p = 0.0252*)	YES (r = -0.848, p = 0.0068*)
9	YES (r = -0.716, p = 0.0408*)	YES (r = -0.802, p = 0.0396*)	YES (r = -0.802, p = 0.0238*)
10	YES (r = -0.677, p = 0.0656*)	YES (r = -0.657, p = 0.0952*)	YES (r = -0.733, p = 0.0800*)
11	YES (r = -0.859, p = 0.0070*)	YES (r = -0.895, p = 0.0008*)	YES (r = -0.844, p = 0.0226*)
12	YES (r = -0.629, p = 0.0760*)	YES (r = -0.836, p = 0.0068*)	

* = p<0.100

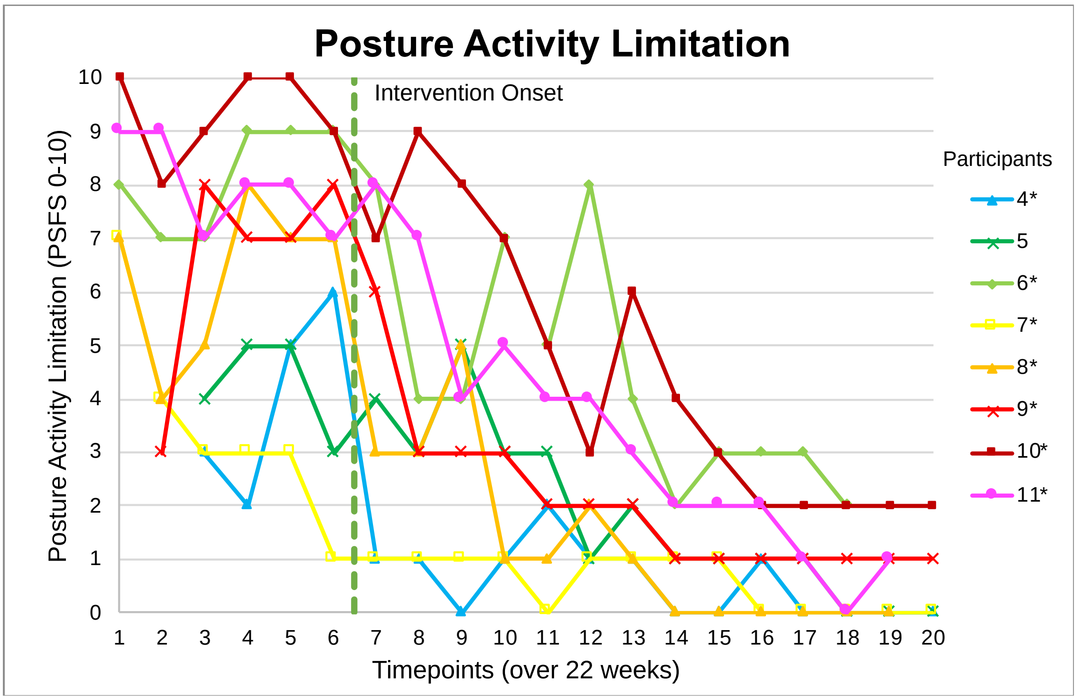
Figure 5-5 Appendix 2. ResultsS1. Change in outcome. Single-case series



Abbreviations: Tri.NRS, mean of current, average and worst pain over last week on 0-10 numerical rating scale. * = p<0.100



Abbreviations: PSFS, patient specific functional scale on 0-10 numerical rating scale (lower = less activity limitation). * = p<0.100



Abbreviations: PSFS, patient specific functional scale on 0-10 numerical rating scale (lower = less activity limitation). * = p<0.100

5.8.3 Appendix 3: TableS2

Table 5.7 Appendix 3. TableS2. Cross-correlation for all time-lags. Single-case series

Table S2a. Cross-correlation[a] analyses for all time-lags[b] (-2 to +2 weeks) for each participant's most disabling PSFS movement.

Participant, PSFS activity and movement parameter			Cross-correlation for all time-lags (-2 to +2)	
			Pain (Tri.NRS)	Activity limitation (PSFS)
P01	Bending	T12_ROM	LAG:-02 r=+0.21 p= 0.203 LAG:-01 r=+0.09 p= 0.376 **LAG:0 r=-0.48 p= 0.034** LAG:+01 r=-0.33 p= 0.097 LAG: +02 r=-0.25 p= 0.172	LAG:-02 r=+0.22 p= 0.212 LAG:-01 r=+0.08 p= 0.368 LAG:0 r=+0.01 p= 0.487 LAG:+01 r=-0.06 p= 0.403 LAG: +02 r=+0.11 p= 0.369
		T12_VEL	LAG:-02 r=+0.08 p= 0.328 LAG:-01 r=+0.14 p= 0.302 LAG:0 r=-0.14 p= 0.309 LAG:+01 r=-0.12 p= 0.312 LAG: +02 r=-0.41 p= 0.054	LAG:-02 r=+0.38 p= 0.081 LAG:-01 r=+0.01 p= 0.493 LAG:0 r=+0.33 p= 0.099 LAG:+01 r=+0.23 p= 0.187 LAG: +02 r=-0.29 p= 0.126
P02	Bending	T12_ROM	LAG:-02 r=-0.06 p= 0.403 **LAG:-01 r=-0.54 p= 0.019** **LAG:0 r=-0.78 p= 0.001** LAG:+01 r=-0.23 p= 0.224 LAG: +02 r=+0.06 p= 0.407	LAG:-02 r=-0.08 p= 0.388 LAG:-01 r=-0.32 p= 0.137 **LAG:0 r=-0.78 p= 0.000** LAG:+01 r=-0.26 p= 0.181 LAG: +02 r=+0.03 p= 0.466
		T12_VEL	LAG:-02 r=-0.10 p= 0.369 **LAG:-01 r=-0.52 p= 0.022** **LAG:0 r=-0.68 p= 0.005** LAG:+01 r=-0.15 p= 0.303 LAG: +02 r=+0.20 p= 0.243	LAG:-02 r=-0.14 p= 0.292 LAG:-01 r=-0.39 p= 0.088 **LAG:0 r=-0.80 p= 0.000** LAG:+01 r=-0.23 p= 0.217 LAG: +02 r=+0.24 p= 0.175
		EMG	LAG:-02 r=-0.10 p= 0.350 LAG:-01 r=+0.40 p= 0.078 **LAG:0 r=+0.77 p= 0.002** LAG:+01 r=+0.41 p= 0.078 LAG: +02 r=+0.03 p= 0.471	LAG:-02 r=-0.07 p= 0.383 LAG:-01 r=+0.23 p= 0.215 **LAG:0 r=+0.68 p= 0.008** LAG:+01 r=+0.39 p= 0.065 LAG: +02 r=+0.01 p= 0.488
P03	Bending	T12_ROM	LAG:-02 r=-0.30 p= 0.125 **LAG:-01 r=-0.62 p= 0.012** **LAG:0 r=-0.71 p= 0.004** LAG:+01 r=-0.38 p= 0.106 LAG: +02 r=-0.18 p= 0.291	LAG:-02 r=-0.36 p= 0.096 **LAG:-01 r=-0.54 p= 0.022** **LAG:0 r=-0.77 p= 0.002** **LAG:+01 r=-0.51 p= 0.030** LAG: +02 r=-0.42 p= 0.075
		T12_VEL	LAG:-02 r=-0.11 p= 0.323 LAG:-01 r=-0.37 p= 0.053 **LAG:0 r=-0.53 p= 0.017** LAG:+01 r=-0.36 p= 0.090 LAG: +02 r=-0.10 p= 0.339	LAG:-02 r=-0.21 p= 0.183 LAG:-01 r=-0.26 p= 0.159 **LAG:0 r=-0.65 p= 0.003** **LAG:+01 r=-0.45 p= 0.024** LAG: +02 r=-0.33 p= 0.095
		EMG	LAG:-02 r=-0.24 p= 0.157 LAG:-01 r=-0.07 p= 0.410 LAG:0 r=+0.34 p= 0.073 LAG:+01 r=+0.22 p= 0.184 LAG: +02 r=+0.15 p= 0.276	LAG:-02 r=-0.27 p= 0.117 LAG:-01 r=-0.25 p= 0.148 LAG:0 r=-0.14 p= 0.321 LAG:+01 r=-0.07 p= 0.393 LAG: +02 r=+0.20 p= 0.200
P04	Bending	T12_ROM	LAG:-02 r=-0.22 p= 0.245 LAG:-01 r=-0.27 p= 0.207 LAG:0 r=-0.46 p= 0.073 **LAG:+01 r=-0.59 p= 0.016** LAG: +02 r=-0.35 p= 0.133	LAG:-02 r=-0.26 p= 0.209 LAG:-01 r=-0.43 p= 0.083 **LAG:0 r=-0.69 p= 0.005** **LAG:+01 r=-0.70 p= 0.003** LAG: +02 r=-0.36 p= 0.112
		T12_VEL	LAG:-02 r=-0.08 p= 0.400 LAG:-01 r=-0.23 p= 0.239 **LAG:0 r=-0.58 p= 0.031** **LAG:+01 r=-0.51 p= 0.047** LAG: +02 r=-0.43 p= 0.077	LAG:-02 r=-0.18 p= 0.271 LAG:-01 r=-0.51 p= 0.056 **LAG:0 r=-0.81 p= 0.002** **LAG:+01 r=-0.64 p= 0.016** **LAG: +02 r=-0.54 p= 0.040**

		EMG	LAG:-02 r=-0.00 p= 0.511 LAG:-01 r=+0.02 p= 0.453 LAG:0 r=+0.36 p= 0.106 **LAG:+01 r=+0.68 p= 0.004** LAG:+02 r=+0.45 p= 0.064	LAG:-02 r=+0.16 p= 0.290 LAG:-01 r=+0.20 p= 0.250 **LAG:0 r=+0.53 p= 0.036** **LAG:+01 r=+0.88 p= 0.000** LAG:+02 r=+0.35 p= 0.112
P05	Bending	T12_ROM	LAG:-02 r=-0.46 p= 0.074 **LAG:-01 r=-0.61 p= 0.023** **LAG:0 r=-0.76 p= 0.003** **LAG:+01 r=-0.71 p= 0.002** **LAG: +02 r=-0.70 p= 0.006**	LAG:-02 r=-0.54 p= 0.019 **LAG:-01 r=-0.64 p= 0.006** **LAG:0 r=-0.67 p= 0.006** **LAG:+01 r=-0.49 p= 0.035** LAG: +02 r=-0.36 p= 0.103
		T12_VEL	**LAG:-02 r=-0.39 p= 0.013** LAG:-01 r=+0.12 p= 0.268 LAG:0 r=-0.31 p= 0.067 LAG:+01 r=+0.28 p= 0.057 LAG: +02 r=+0.07 p= 0.357	**LAG:-02 r=-0.39 p= 0.022** LAG:-01 r=+0.17 p= 0.204 LAG:0 r=-0.05 p= 0.411 LAG:+01 r=+0.22 p= 0.155 LAG: +02 r=+0.22 p= 0.133
		EMG	LAG:-02 r=-0.04 p= 0.404 LAG:-01 r=+0.17 p= 0.196 LAG:0 r=+0.22 p= 0.146 LAG:+01 r=+0.13 p= 0.261 **LAG: +02 r=+0.35 p= 0.041**	LAG:-02 r=-0.05 p= 0.408 LAG:-01 r=+0.18 p= 0.201 LAG:0 r=+0.33 p= 0.069 LAG:+01 r=-0.06 p= 0.405 LAG: +02 r=+0.30 p= 0.071
P06	Lifting	T12_ROM	LAG:-02 r=-0.19 p= 0.274 LAG:-01 r=-0.44 p= 0.080 **LAG:0 r=-0.64 p= 0.014** **LAG:+01 r=-0.51 p= 0.041** **LAG: +02 r=-0.69 p= 0.005**	LAG:-02 r=-0.20 p= 0.293 LAG:-01 r=-0.42 p= 0.118 **LAG:0 r=-0.65 p= 0.023** **LAG:+01 r=-0.70 p= 0.006** **LAG: +02 r=-0.72 p= 0.005**
		T12_VEL	**LAG:-02 r=-0.51 p= 0.045** **LAG:-01 r=-0.59 p= 0.030** **LAG:0 r=-0.72 p= 0.008** **LAG:+01 r=-0.62 p= 0.015** **LAG: +02 r=-0.71 p= 0.003**	**LAG:-02 r=-0.51 p= 0.047** **LAG:-01 r=-0.55 p= 0.043** **LAG:0 r=-0.79 p= 0.001** **LAG:+01 r=-0.65 p= 0.017** **LAG: +02 r=-0.65 p= 0.010**
P07	Bending	T12_ROM	LAG:-02 r=+0.32 p= 0.081 LAG:-01 r=+0.24 p= 0.150 **LAG:0 r=+0.55 p= 0.004** **LAG:+01 r=+0.48 p= 0.018** LAG: +02 r=+0.36 p= 0.063	LAG:-02 r=+0.30 p= 0.099 LAG:-01 r=+0.28 p= 0.123 **LAG:0 r=+0.52 p= 0.012** **LAG:+01 r=+0.40 p= 0.042** LAG: +02 r=+0.35 p= 0.059
		T12_VEL	LAG:-02 r=-0.24 p= 0.146 **LAG:-01 r=-0.41 p= 0.036** LAG:0 r=-0.35 p= 0.077 LAG:+01 r=-0.40 p= 0.060 LAG: +02 r=-0.09 p= 0.350	LAG:-02 r=-0.27 p= 0.133 LAG:-01 r=-0.26 p= 0.136 **LAG:0 r=-0.44 p= 0.050** LAG:+01 r=-0.34 p= 0.086 LAG: +02 r=-0.22 p= 0.192
		EMG	LAG:-02 r=-0.21 p= 0.149 LAG:-01 r=-0.04 p= 0.412 LAG:0 r=-0.24 p= 0.120 LAG:+01 r=-0.18 p= 0.204 LAG: +02 r=+0.02 p= 0.445	LAG:-02 r=-0.13 p= 0.236 LAG:-01 r=-0.05 p= 0.390 LAG:0 r=-0.18 p= 0.179 LAG:+01 r=-0.18 p= 0.185 LAG: +02 r=-0.02 p= 0.466
P08	Bending	T12_ROM	LAG:-02 r=-0.28 p= 0.190 **LAG:-01 r=-0.55 p= 0.042** **LAG:0 r=-0.65 p= 0.020** **LAG:+01 r=-0.66 p= 0.013** **LAG: +02 r=-0.69 p= 0.006**	LAG:-02 r=-0.39 p= 0.106 **LAG:-01 r=-0.57 p= 0.031** **LAG:0 r=-0.64 p= 0.020** **LAG:+01 r=-0.65 p= 0.017** **LAG: +02 r=-0.65 p= 0.015**
		T12_VEL	**LAG:-02 r=-0.52 p= 0.080** **LAG:-01 r=-0.71 p= 0.020** **LAG:0 r=-0.86 p= 0.003** **LAG:+01 r=-0.84 p= 0.001** **LAG: +02 r=-0.81 p= 0.000**	**LAG:-02 r=-0.57 p= 0.042** **LAG:-01 r=-0.70 p= 0.015** **LAG:0 r=-0.81 p= 0.005** **LAG:+01 r=-0.78 p= 0.011** **LAG: +02 r=-0.76 p= 0.003**
		EMG	LAG:-02 r=+0.27 p= 0.132 LAG:-01 r=+0.42 p= 0.051 **LAG:0 r=+0.45 p= 0.047** **LAG:+01 r=+0.52 p= 0.015** LAG: +02 r=+0.32 p= 0.099	LAG:-02 r=+0.30 p= 0.107 **LAG:-01 r=+0.43 p= 0.035** **LAG:0 r=+0.45 p= 0.037** **LAG:+01 r=+0.53 p= 0.013** LAG: +02 r=+0.33 p= 0.087
P09	Bending	T12_ROM	**LAG:-02 r=-0.64 p= 0.016** LAG:-01 r=-0.43 p= 0.099 LAG:0 r=-0.36 p= 0.137 LAG:+01 r=-0.13 p= 0.347 LAG: +02 r=+0.05 p= 0.431	**LAG:-02 r=-0.69 p= 0.006** **LAG:-01 r=-0.54 p= 0.039** LAG:0 r=-0.32 p= 0.184 LAG:+01 r=-0.16 p= 0.319 LAG: +02 r=+0.07 p= 0.425

		T12_VEL	**LAG:-02 r=-0.53 p= 0.038** **LAG:-01 r=-0.63 p= 0.014** **LAG:0 r=-0.70 p= 0.010** **LAG:+01 r=-0.81 p= 0.000** **LAG: +02 r=-0.65 p= 0.010**	**LAG:-02 r=-0.56 p= 0.062** **LAG:-01 r=-0.64 p= 0.030** **LAG:0 r=-0.77 p= 0.008** **LAG:+01 r=-0.79 p= 0.000** **LAG: +02 r=-0.80 p= 0.000**
		EMG	**LAG:-02 r=+0.62 p= 0.011** **LAG:-01 r=+0.64 p= 0.006** **LAG:0 r=+0.91 p= 0.000** **LAG:+01 r=+0.52 p= 0.027** LAG: +02 r=+0.45 p= 0.050	**LAG:-02 r=+0.64 p= 0.007** **LAG:-01 r=+0.82 p= 0.000** **LAG:0 r=+0.80 p= 0.002** **LAG:+01 r=+0.69 p= 0.004** LAG: +02 r=+0.45 p= 0.083
P10	Bending	T12_ROM	LAG:-02 r=+0.35 p= 0.075 LAG:-01 r=+0.19 p= 0.249 LAG:0 r=+0.41 p= 0.060 LAG:+01 r=+0.24 p= 0.162 LAG: +02 r=+0.00 p= 0.494	**LAG:-02 r=+0.40 p= 0.047** LAG:-01 r=+0.16 p= 0.245 LAG:0 r=+0.37 p= 0.069 LAG:+01 r=+0.12 p= 0.324 LAG: +02 r=-0.07 p= 0.375
		T12_VEL	LAG:-02 r=-0.03 p= 0.456 LAG:-01 r=-0.32 p= 0.113 LAG:0 r=-0.34 p= 0.068 LAG:+01 r=-0.26 p= 0.152 **LAG: +02 r=-0.49 p= 0.015**	LAG:-02 r=-0.06 p= 0.400 LAG:-01 r=-0.35 p= 0.072 LAG:0 r=-0.27 p= 0.138 LAG:+01 r=-0.26 p= 0.146 **LAG: +02 r=-0.44 p= 0.032**
		EMG	LAG:-02 r=-0.07 p= 0.348 LAG:-01 r=-0.18 p= 0.224 LAG:0 r=-0.10 p= 0.346 LAG:+01 r=-0.26 p= 0.128 LAG: +02 r=-0.32 p= 0.065	LAG:-02 r=-0.20 p= 0.192 LAG:-01 r=-0.26 p= 0.131 LAG:0 r=-0.25 p= 0.121 LAG:+01 r=-0.23 p= 0.109 LAG: +02 r=-0.24 p= 0.128
P11	Bending	T12_ROM	LAG:-02 r=-0.57 p= 0.052 **LAG:-01 r=-0.76 p= 0.011** **LAG:0 r=-0.86 p= 0.000** **LAG:+01 r=-0.80 p= 0.005** **LAG: +02 r=-0.72 p= 0.007**	**LAG:-02 r=-0.69 p= 0.016** **LAG:-01 r=-0.82 p= 0.002** **LAG:0 r=-0.91 p= 0.000** **LAG:+01 r=-0.75 p= 0.006** **LAG: +02 r=-0.61 p= 0.030**
		T12_VEL	**LAG:-02 r=-0.70 p= 0.011** **LAG:-01 r=-0.81 p= 0.003** **LAG:0 r=-0.88 p= 0.000** **LAG:+01 r=-0.84 p= 0.001** **LAG: +02 r=-0.69 p= 0.017**	**LAG:-02 r=-0.75 p= 0.003** **LAG:-01 r=-0.83 p= 0.003** **LAG:0 r=-0.87 p= 0.001** **LAG:+01 r=-0.75 p= 0.010** **LAG: +02 r=-0.58 p= 0.041**
P12	Bending	T12_ROM	LAG:-02 r=-0.32 p= 0.126 LAG:-01 r=-0.38 p= 0.082 **LAG:0 r=-0.53 p= 0.025** **LAG:+01 r=-0.53 p= 0.021** **LAG: +02 r=-0.57 p= 0.011**	LAG:-02 r=-0.39 p= 0.077 **LAG:-01 r=-0.52 p= 0.033** **LAG:0 r=-0.55 p= 0.041** **LAG:+01 r=-0.54 p= 0.042** **LAG: +02 r=-0.53 p= 0.035**
		T12_VEL	LAG:-02 r=-0.40 p= 0.094 LAG:-01 r=-0.51 p= 0.050 **LAG:0 r=-0.62 p= 0.013** LAG:+01 r=-0.33 p= 0.150 **LAG: +02 r=-0.48 p= 0.045**	LAG:-02 r=-0.35 p= 0.095 **LAG:-01 r=-0.49 p= 0.034** **LAG:0 r=-0.65 p= 0.004** **LAG:+01 r=-0.54 p= 0.018** **LAG: +02 r=-0.58 p= 0.016**
		EMG	LAG:-02 r=+0.14 p= 0.249 LAG:-01 r=+0.11 p= 0.335 **LAG:0 r=+0.77 p= 0.000** LAG:+01 r=+0.27 p= 0.134 LAG: +02 r=+0.30 p= 0.103	**LAG:-02 r=+0.58 p= 0.003** **LAG:-01 r=+0.57 p= 0.005** **LAG:0 r=+0.50 p= 0.011** **LAG:+01 r=+0.60 p= 0.002** LAG: +02 r=+0.20 p= 0.197

Abbreviations: T12_ROM, T12 Range of motion; T12_VEL, T12 angular velocity; EMG, lumbar muscle Electromyography

[a] Cross-correlation analyses performed using Simulation Modelling Analysis.

[b] A lag of zero indicates the two variables likely occurred together, a positive lag indicates that a change in movement or posture likely preceded a change in pain or activity limitation, and a negative lag indicates that a change in movement or posture likely followed a change in pain or activity limitation.

TableS2b. Cross-correlation[a] analyses for all time-lags[b] (-2 to +2 weeks) for each participant's most disabling posture.

Participant, PSFS activity and postural parameter			Cross-correlation for all time-lags (-2 to +2)	
			Pain (Tri.NRS)	Activity limitation (PSFS)
P04	Sitting	S2_Angle	LAG:-02 r=+0.21 p= 0.227 LAG:-01 r=+0.31 p= 0.158 LAG:0 r=+0.24 p= 0.224 LAG:+01 r=+0.37 p= 0.105 LAG:+02 r=-0.04 p= 0.449	**LAG:-02 r=+0.50 p= 0.020** LAG:-01 r=+0.42 p= 0.057 **LAG:0 r=+0.60 p= 0.016** **LAG:+01 r=+0.52 p= 0.032** LAG:+02 r=+0.06 p= 0.423
P05	Sitting	S2_Angle	LAG:-02 r=+0.18 p= 0.198 LAG:-01 r=+0.14 p= 0.278 LAG:0 r=-0.02 p= 0.487 LAG:+01 r=+0.01 p= 0.503 LAG: +02 r=+0.09 p= 0.346	LAG:-02 r=+0.26 p= 0.108 LAG:-01 r=+0.09 p= 0.317 LAG:0 r=-0.01 p= 0.481 LAG:+01 r=-0.14 p= 0.258 LAG: +02 r=+0.13 p= 0.238
P06	Sitting	S2_Angle	LAG:-02 r=+0.07 p= 0.426 LAG:-01 r=+0.17 p= 0.323 LAG:0 r=+0.28 p= 0.210 LAG:+01 r=+0.51 p= 0.053 **LAG: +02 r=+0.63 p= 0.005**	LAG:-02 r=+0.06 p= 0.421 LAG:-01 r=+0.13 p= 0.340 LAG:0 r=+0.29 p= 0.187 LAG:+01 r=+0.43 p= 0.077 **LAG: +02 r=+0.58 p= 0.017**
P07	Sitting	S2_Angle	**LAG:-02 r=-0.48 p= 0.020** **LAG:-01 r=-0.59 p= 0.004** **LAG:0 r=-0.43 p= 0.041** LAG:+01 r=-0.36 p= 0.068 LAG: +02 r=-0.29 p= 0.118	**LAG:-02 r=-0.64 p= 0.002** **LAG:-01 r=-0.59 p= 0.008** **LAG:0 r=-0.56 p= 0.015** LAG:+01 r=-0.34 p= 0.093 LAG: +02 r=-0.35 p= 0.081
P08	Standing	S2_Angle	LAG:-02 r=+0.19 p= 0.146 LAG:-01 r=+0.30 p= 0.056 LAG:0 r=+0.25 p= 0.090 LAG:+01 r=+0.27 p= 0.068 LAG: +02 r=+0.22 p= 0.100	LAG:-02 r=+0.15 p= 0.214 LAG:-01 r=+0.17 p= 0.183 **LAG:0 r=+0.37 p= 0.035** LAG:+01 r=+0.24 p= 0.113 LAG: +02 r=+0.15 p= 0.235
P09	Sustained extension	S2_Angle	LAG:-02 r=-0.19 p= 0.177 LAG:-01 r=-0.26 p= 0.102 LAG:0 r=-0.02 p= 0.437 LAG:+01 r=+0.07 p= 0.374 LAG: +02 r=-0.05 p= 0.396	LAG:-02 r=-0.20 p= 0.141 LAG:-01 r=-0.25 p= 0.092 LAG:0 r=-0.34 p= 0.051 LAG:+01 r=+0.01 p= 0.493 LAG: +02 r=-0.07 p= 0.367
P10	Standing	S2_Angle	LAG:-02 r=-0.04 p= 0.423 LAG:-01 r=+0.01 p= 0.510 LAG:0 r=-0.02 p= 0.447 LAG:+01 r=-0.04 p= 0.406 LAG: +02 r=+0.11 p= 0.304	LAG:-02 r=+0.01 p= 0.460 LAG:-01 r=-0.08 p= 0.321 LAG:0 r=+0.04 p= 0.410 LAG:+01 r=+0.03 p= 0.441 LAG: +02 r=+0.09 p= 0.324
P11	Standing	S2_Angle	**LAG:-02 r=+0.65 p= 0.010** **LAG:-01 r=+0.71 p= 0.003** **LAG:0 r=+0.79 p= 0.002** **LAG:+01 r=+0.72 p= 0.011** **LAG: +02 r=+0.55 p= 0.039**	**LAG:-02 r=+0.59 p= 0.023** **LAG:-01 r=+0.79 p= 0.000** **LAG:0 r=+0.77 p= 0.005** **LAG:+01 r=+0.78 p= 0.004** **LAG: +02 r=+0.60 p= 0.021**

Abbreviations: T12_ROM, T12 Range of motion; T12_VEL, T12 angular velocity; EMG, lumbar muscle Electromyography

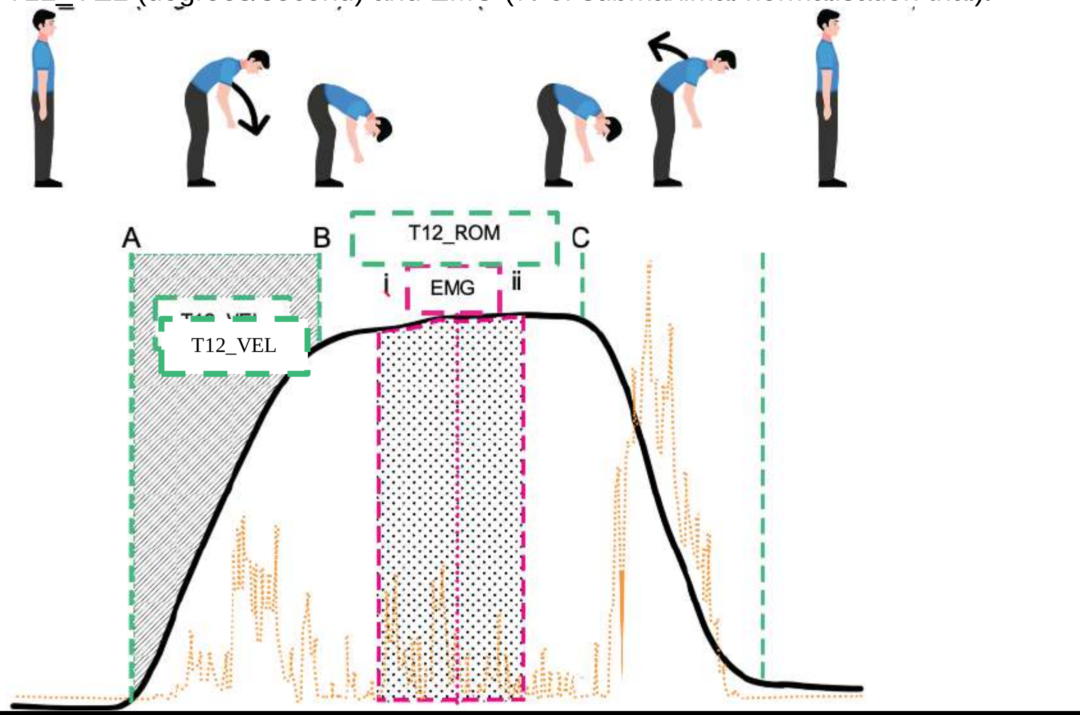
[a] Cross-correlation analyses performed using Simulation Modelling Analysis.

[b] A lag of zero indicates the two variables likely occurred together, a positive lag indicates that a change in movement or posture likely *preceded* a change in pain or activity limitation, and a negative lag indicates that a change in movement or posture likely *followed* a change in pain or activity limitation.

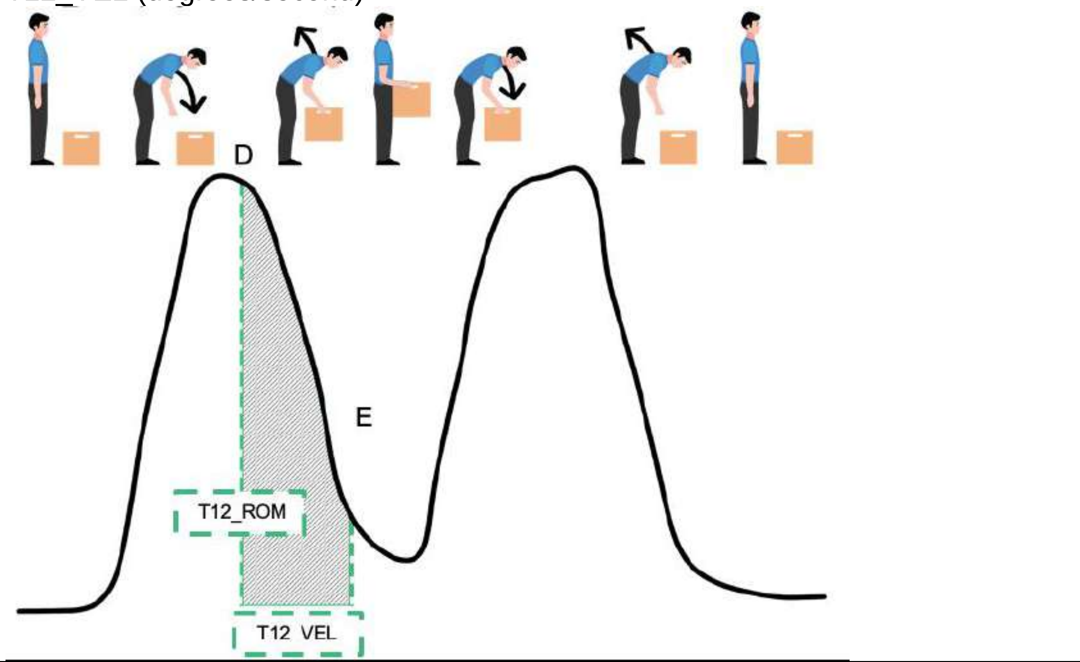
5.8.4 Appendix 4: MethodsS1

MethodsS1. The movement and postural parameters and explanation of IMU and EMG analysis.

Bending. The parameters analysed during bending; T12_ROM (degrees), T12_VEL (degrees/second) and EMG (% of submaximal normalisation trial).



Lifting. The parameters analysed during lifting; T12_ROM (degrees) and T12_VEL (degrees/second)



Abbreviations: T12_ROM, T12 Range of motion; T12_VEL, T12 angular velocity; EMG, lumbar muscle Electromyography

Key: Solid black line (▬) = T12_ROM, Orange line (⋯⋯) = EMG

Table 5.8 **Appendix 4. MethodsS1. Movement and postural parameter description. Single-case series**

Activity	Movement or postural Parameter	Description	Phase Start	Phase End
Forward bending	T12_ROM	Peak global flexion angle of the thoracolumbar (T12) sensor during bending at a self-selected speed, holding for five seconds, and returning	Flexion angular velocity of Thoracolumbar (T12) sensor falls below 7°/second (Laird, Keating, Ussing, Li, & Kent, 2019) **(B)**	Extension angular velocity of Thoracolumbar (T12) sensor exceeds 7°/second (Laird et al., 2019) **(C)**
	T12_VEL	Mean angular velocity of thoracolumbar (T12) sensor during bending phase	Flexion angular velocity of Thoracolumbar (T12) sensor exceeds 7°/second (Laird et al., 2019) **(A)**	Flexion angular velocity of Thoracolumbar (T12) sensor falls below 7°/second (Laird et al., 2019) **(B)**
	EMG	Mean surface EMG activity during the middle 3 seconds of maximal voluntary trunk flexion. Normalised to 5 seconds of sub-maximal isometric hip extension in prone.	1 second before the midpoint of the end of range bending (bendhold) phase **(i)**	1 second after the midpoint of the end of range bending (bendhold phase) **(ii)**
Lifting[a]	T12_ROM	Global flexion angle of the thoracolumbar sensor at the commencement of lifting a 10kg* crate.	Extension angular velocity of thoracolumbar (T12) sensor exceeds 7°/second (Laird et al., 2019)) **(D)**	N/A
	T12_VEL	Mean angular velocity of the thoracolumbar sensor while lifting a 10kg* crate	Extension angular velocity of thoracolumbar (T12) sensor exceeds 7°/second (Laird et al., 2019)) **(D)**	Extension angular velocity of thoracolumbar (T12) sensor falls below 7°/second (Laird et al., 2019)) **(E)**
Sitting	S2_Angle	Mean global angle of upper sacrum (S2) sensor during 15 seconds of self-selected sitting posture	Commencement of self-selected sitting posture	Conclusion of self-selected sitting posture

Standing	S2_Angle	Mean global angle of upper sacrum (S2) sensor during 15 seconds of self-selected standing posture	Commencement of self-selected standing posture	Conclusion of self-selected standing posture
Sustained extension (looking up ladder)	T12_Angle	Mean global angle of thoracolumbar (T12) sensor during two trials of 15 seconds of extension simulating a patient specific activity	Commencement of extension activity	Conclusion of extension activity

[a] Participants lifted both an empty crate and a crate with 10kg inside it.
Abbreviations: T12_ROM, T12 Range of motion; T12_VEL, T12 angular velocity; EMG, lumbar muscle Electromyography

Explanation of inertial measurement unit (IMU) and EMG analysis

The IMUs were sampling at 20Hz. The raw, three-dimensional accelerometer, gyroscope and magnetometer data were used to estimate each sensor's orientation (initially represented by quaternions using the most up-to-date algorithm available from the sensor company). A program written in LabVIEW (National Instruments, Richardson, TX) then converted the quaternions into Euler angles, using a flexion extension/lateral flexion/rotation 'order of rotations'. This program also allowed the sagittal plane orientation (or angle) of each sensor to be viewed during selected time periods, such that more refined 'movement phase' selection could take place (outlined in above table**)**.

The EMG activity was collected at 300Hz and down sampled to 20Hz. EMG signals were amplified to a gain setting of 9660V/V, band-pass filtered (20-300Hz), rectified and enveloped at 5Hz, and the scaled (1024 counts divided by 10). This field-based EMG system has successfully discriminated between people without LBP and people with LBP (and LBP subgroups) in previous studies despite demonstrating a lower sampling rate and heavy filtering process compared to traditional laboratory-based EMG systems (Laird et al., 2018, Laird et al., 2019). Three sub-maximal isometric trials involving five seconds of hip extension in prone with the knees at 90° (Dankaerts et al., 2004) were performed at the start of each data collection session. Normalising to sub-maximal isometric contractions provides greater reliability compared to maximal isometric contractions when assessing EMG activity between days (Dankaerts et al., 2004).

Most representative movement or postural parameters

For movement activities, our judgement was that the range and velocity of the *thoracolumbar (T12) sensor* would offer the most concise and representative measure of the participant's movement. These parameters were also frequently targeted by the physiotherapists. Additionally, for bending, the mean normalised EMG activity from the lumbar muscles during end of range bending was analysed. The middle two seconds of EMG activity at maximum voluntary flexion was normalised to an isometric, sub-maximal contraction (lying prone with knees flexed to 90 degrees and lifting the knees approximately five centimetres for five seconds) (Dankaerts et al., 2004). This allowed the comparison of EMG activity for individuals over time. An additional consideration was that we expected participants to increase their velocity over the 22-week study period, which may influence the EMG activity during flexion. If using the traditional FRR, the increased activity during the faster flexion movement would bias towards a false positive finding of greater flexion relaxation (given the relaxation activity remained constant) when the participant was simply moving faster and not 'relaxing more'. That is an additional reason why we normalised to sub-maximal isometric contractions.

For static postures, it our judgement that the most representative and concise measure during sitting and standing, and the one frequently targeted by the physiotherapists, was the upper-sacrum sensor. Due to the native filtering of the EMG signal by the sensor company, EMG activity during static tasks was not amenable to analysis. For the Patient Specific Functional Scale task of sustained extension for P09, the T12 sensor was deemed the most representative measure.

References for MethodsS1

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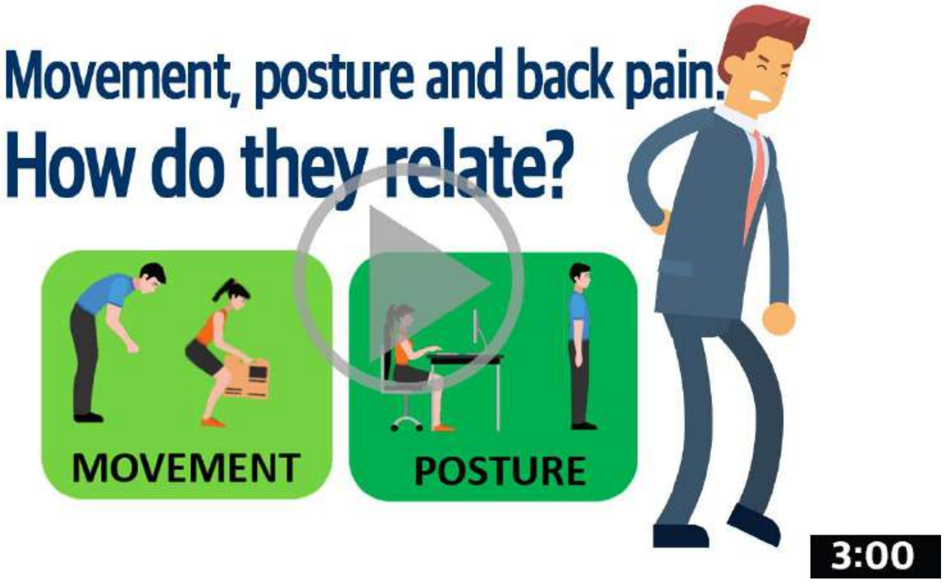
Laird, R. A., Keating, J. L., & Kent, P. (2018). Subgroups of lumbo-pelvic flexion kinematics are present in people with and without persistent low back pain. *BMC Musculoskeletal Disorders, 19*(1), 309. https://doi.org/10.1186/s12891-018-2233-1

Laird, R. A., Keating, J. L., Ussing, K., Li, P., & Kent, P. (2019). Does movement matter in people with back pain? Investigating 'atypical' lumbo-pelvic kinematics in people with and without back pain using wireless movement sensors. *BMC Musculoskeletal Disorders, 20*(1), 28. https://doi.org/10.1186/s12891-018-2387-x

5.8.5 Appendix 5: Video Abstract Supplementary File

Following discussions with the European Journal of Pain editorial board, we have produced a video abstract to accompany the manuscript. It can be found by following the link below.



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Chapter 6 Mixed methods

From protection to non-protection: A mixed methods replicated single-case series investigating movement and posture in 12 people with disabling low back pain undergoing Cognitive Functional Therapy

The findings from the previous two systematic reviews and the single-case series presented in Chapters 3, 4, and 5 suggest that when changes in movement and posture are related to changes in LBP, quantitative measures of movement and posture consistently return towards less protective patterns as people with LBP improve. But how people with LBP *conceptualise* the relationship between movement, posture, and their LBP as they improve remains unknown. Qualitative interviews can garner complementary, rich, and clinically relevant insights, and, when integrated with quantitative findings, can provide more comprehensive insights about a subject (Fetters & Molina-Azorin, 2019).

This chapter reports a mixed-methods investigation into how 12 people with persistent, disabling low back pain *conceptualise* the relationship between movement, posture, and LBP. Qualitative findings from interviews conducted before and after a Cognitive Functional Therapy intervention were integrated with quantitative changes in movement, posture, pain, activity limitation, and psychological factors. This study is under currently under review and will be presented in its submitted format and in accordance with that journal's author instructions.

Qualitative methodology

To answer questions about how people with persistent, disabling non-specific LBP *conceptualise* the relationship between movement, posture, and their LBP before and after rehabilitation, we employed a qualitative approach. In contrast to quantitative approaches, where a singular answer ('truth') to research questions exists (an underlying paradigm called 'positivism' that is assumed and rarely stated), qualitative approaches encourage the researchers to make the underlying paradigm explicit, as the assumptions related to these can form an important part of the research process (Guba & Lincoln, 2005). All research (quantitative and qualitative) is underpinned by an *ontology* and *epistemology*. While this thesis did not focus heavily on using a qualitative approach, and therefore qualitative underpinnings and terminology will not be discussed in detail, my assumptions, beliefs, and worldview shape my actions and interpretations as a researcher (Flick, 2013), and are therefore important considerations. I drew on the SAGE Handbook of Qualitative Research to develop my understanding of qualitative underpinnings and terminology (Denzin & Lincoln, 2017). While the mode of inquiry and qualitative analysis (interpretive description as outlined by Thorne et al. (1997)) used in the mixed-methods design presented in this chapter have been introduced in Section 2.5.2, the methodological assumptions that underpin this mode of inquiry will be briefly introduced below.

Ontology refers to what reality '*is'* – the assumptions about the nature of reality (Flick, 2013). The aim of the qualitative research in this thesis was to acquire knowledge about subjective experiences, perceptions, and conceptualisations about movement and posture in people with LBP. The experiences are likely to vary between people, with the influencing factors expected to be complex and multidimensional. In this way, there is no single 'truth' out there to be discovered, rather, reality is created by each person and exists in different constructions for different people (Lincoln et al., 2011). Because reality is considered an individual human experience, a relativist, or subjective, ontology presents as the most appropriate lens from which to view reality.

Epistemology refers to *knowledge* – how knowledge is acquired, studied, and what knowledge is (Denzin & Lincoln, 2017). Given the subjective ontology (relativism) of the conceptualisations of people with LBP about movement and posture, a constructivist epistemology that assumes ever changing multidimensional realities appears most appropriate (Guba & Lincoln, 2005). A constructivist epistemology assumes that both the people with LBP and myself as the researcher *construct* the world around us based on our unique experiences (Guba & Lincoln, 2005). It also embraces the subjectivity of knowledge and accommodates important social contexts (Guba & Lincoln, 2005).

In constructivism, meaning is co-constructed between the participant and the researcher, and it is acknowledged that the researcher forms part of the research process (this is not undesirable) (Bryant & Charmaz, 2010). Thus, my lens and that of the research team (which include clinical and research physiotherapists and a biomechanist) is not diminished or negated (Guba & Lincoln, 2005). However, to ensure the findings remained grounded in the participants' stories, rather than my own clinical lens, I maintained reflexive accounts and employed other methods to ensure trustworthiness. Reflexivity, a common process in qualitative approaches, is especially important when considering the acquisition of subjective knowledge (Guba & Lincoln, 2005).

Qualitative methods

In quantitative positivist paradigms, enhancing scientific rigour can be accomplished by ensuring designs have high internal and external validity, using valid and reliable tools, and remaining objective (Amin et al., 2020) (Lincoln & Guba, 1985). The different ontological and epistemological underpinnings of qualitative research necessitate different quality criteria. Lincoln and Guba (1985) proposed a parallel criterion to ensure scientific quality and rigour (termed *trustworthiness*) among qualitative approaches. They suggested credibility, transferability, dependability, and confirmability be used as qualitative equivalents to internal validity, external validity, reliability, and objectivity respectively (Lincoln & Guba, 1985). Lincoln and Guba also proposed criteria to ensure the participants voices were *realistically* and *fairly* conveyed (termed *authenticity*) (Lincoln & Guba, 1985) (Amin et al., 2020). The methods we employed to ensure qualitative *trustworthiness* and *authenticity* are described below. These allow the reader to have confidence in the data collection, interpretation, and the methods used.

Trustworthiness

I aimed to see all possible meanings presented by the participants during their interviews. To manage personal bias due to my position as a mid-20s male physiotherapist with some exposure to Cognitive Functional Therapy and knowledge about the movement, posture, and LBP literature, I kept personal reflections and reflexive memos. Reflexivity was also maintained through frequent (fortnightly) meetings with the supervisory group throughout the research process to discuss my assumptions and interpretations (see Thesis Appendix F.1).

The first qualitative interview with each participant occurred throughout the five-week baseline period of the study. By the time of the first interview, I had already completed several movement assessment sessions with each participant that each lasted approximately 30 minutes. In addition to the screening phone call to confirm eligibility, these data collection sessions allowed me to develop rapport and spend time learning about each participants' personal contexts. Additionally, it gave me time to reflect on potential personal and participant distortions that may impact the interviews and findings. This *prolonged engagement* with the participants is a key technique to ensure credibility and therefore trustworthiness in qualitative approaches (Amin et al., 2020; Lincoln & Guba, 1985; Lincoln & Guba, 1986).

Following the interviews, I reflected on the interview, using memos to facilitate this process (see Thesis Appendix F.3). Each interview was then transcribed verbatim. Whilst I initially sought to transcribe the interviews myself, time constraints led to approximately 70% of the transcripts being professionally transcribed by tripleatranscription.com.au. The transcript file and audio files were stored together (see Thesis Appendix F.2). I first listened to each interview in its entirety, making memos in the MAXQDA software (VERBI Software, 2019, Berlin, Germany) throughout the transcript. I made a summary memo at the end of the transcript (see Thesis Appendix F.3). The use of memos assisted me to be reflexive in my interpretations of the data. Reflexivity enhances all aspects of trustworthiness in qualitative research (credibility, transferability, dependability, and confirmability) (Amin et al., 2020; Lincoln & Guba, 1986). I then openly coded the data under broad categories of the Common Sense Model, developing a code book (see Thesis Appendix F.4) that was discussed with the research group at the fortnightly meetings. Discussions among the research group, with the treating physiotherapists, and with other PhD candidates facilitated my consideration of the data from differing perspectives. Such peer debriefing methods further enhance the credibility and trustworthiness of our findings (Amin et al., 2020; Lincoln & Guba, 1986).

The analysis process was cyclical and iterative. It involved prolonged engagement, constant comparison, and multiple re-examinations of the data from varying perspectives. This ensured the participant's voices were accurately represented and our interpretations were grounded in the raw data, enhancing credibility. Baseline and follow-up transcripts from three diverse participants (six transcripts in total) were also coded by a doctoral candidate researching and working clinically in a cardiopulmonary physiotherapy setting. This researcher had some experience in musculoskeletal physiotherapy but no exposure to Cognitive Functional Therapy. Multiple meetings discussing and comparing our open inductive coding took place between the two of us to compare and reflect on coding approaches (see Thesis Appendix F.5). Additionally, these six transcripts were also coded by two of my supervisors who have experience in qualitative research and, as a result, the code book underwent several iterations. This cross coding and peer review process was a further step to reflect on how each researcher coded the transcripts, made assumptions, or may have overlooked aspects of the data (Braun & Clarke, 2020).

To assist in the inter-subject analysis as part of the interpretive description approach (Thorne et al., 1997), I produced summaries and early figures (see Thesis Appendix F.6). These helped to understand important themes and stimulate discussion among the research group. Throughout the analysis process we searched for negative or divergent cases and experiences (for example, by using green asterisks in the charting of inter-person data in 6.13.2). We also provide example quotes to help justify each participants group membership at follow-up (see Thesis Appendix F.7), as well as quotes to demonstrate alignment with the participants' voices and our findings. Together, the above-mentioned techniques aimed to ensure our findings were credible and trustworthy.

Once the research group felt the participants' voices were accurately represented and we reached data saturation (no new themes relating to our research question were identified), the findings were finalised. To assist the reader in transferring the findings of the study, we provided detailed descriptions of each participant, the setting, clinical contexts, and quotes (see Section 6.3.2: Participants, Section 6.3.3: Setting, and Section 6.13.3.1: Detailed descriptions of each participant). Providing detailed descriptions (also referred to as 'thick description') is a key technique to enhance the transferability of the findings (Lincoln & Guba, 1986).

Dependability refers to how repeatable the findings are if the qualitative inquiry were to be repeated within the same cohort of participants, coders, and contexts (Lincoln & Guba, 1985) (Forero et al., 2018). To enhance dependability, I maintained an audit trail (see Thesis Appendix F), with memos and meeting agendas documenting the data analysis process over time.

In contrast to examining the *process* (dependability), confirmability refers to the degree of which the *product* (the findings) could be corroborated by other researchers (Amin et al., 2020; Lincoln & Guba, 1985). Through constant reflexivity and the maintenance of an audit trail documenting the decisions, thoughts, and data analysis process (see Thesis Appendix F), I am confident that another researcher would derive comparable findings. Further, similar findings have been observed in previous qualitative literature (Bunzli, McEvoy, et al., 2016; Bunzli et al., 2017; Bunzli, Smith, Schütze, et al., 2015; Pugh & Williams, 2014), demonstrating consistency in the findings.

Authenticity

In addition to ensuring trustworthiness, we also employed methods to ensure we realistically and fairly conveyed the participants perspectives - referred to as *authenticity*. We endeavoured to sample a diverse population. Our broad inclusion criteria meant we included people who would have traditionally been excluded from studies with more stringent sampling criteria (He et al., 2020). For example, we included those with comorbid mental ill-health, aged over 65 years old, or with a history of spinal surgery, criteria that would have resulting in some of the participants in our study ineligible for many historical studies, such as RCTs (Hill et al., 2011; UK Beam Trial Team, 2004).

Several processes aimed to provide an environment where the participant felt they could speak safely, honestly, without prejudice, and authentically. These included the opportunity for participants to ask questions or withdraw at any time. Similarly, the stringent risk mitigation strategies (such as arrangement of psychological support if required); provision of a participant information sheet (see Thesis Appendix D.1); need for written informed consent (see Thesis Appendix D.2); and confidential data storage that were required for ethical approval further ensured a safe environment (see Thesis Appendix C for ethics approval letter). Finally, the extended time that I spent with the participants allowed me to build rapport which I believe created a situation where participants felt their views were valued and heard. My perception was that they felt they could speak openly and authentically without feeling like they had to say the 'right thing' or what they thought I wanted to hear.

Through the data collection and analysis processes described above, I believe we have portrayed the participant's voices in a trustworthy, authentic, and clinically meaningful way. We also consulted several mixed methods checklists and the consolidated criteria for reporting qualitative research (COREQ) checklist (see Thesis Appendix F.8) in the preparation of the manuscript (Fetters & Freshwater, 2015; Fetters & Molina-Azorin, 2019; Hong et al., 2018; Tong et al., 2007).

The following manuscript is currently under review*.*

Wernli, K., Smith, A., Coll, F., Campbell, A., Kent, P., O'Sullivan P.

From protection to non-protection: A mixed methods replicated single-case series investigating movement and posture in 12 people with disabling low back pain undergoing Cognitive Functional Therapy

6.1 Abstract

Movement and posture are commonly believed to relate to low back pain (LBP). Yet, we know little about how people with LBP conceptualise the relationship between their LBP, movement, and posture, particularly after recovery. We conducted a pre-post convergent mixed method study in the context of an existing replicated single-case design involving 12 people with persistent, disabling non-specific LBP. Findings from qualitative interviews before and after a 12-week physiotherapy-led Cognitive Functional Therapy intervention were integrated with individualised, quantitative measures of movement, posture, pain, activity limitation, and psychological factors. Interpretive description revealed strong movement and postural beliefs during the baseline interviews. Lived experiences of tension and stiffness characterised the embodiment of 'nonconscious protection', while healthcare and societal messages prompted 'conscious protection'. This was associated with fear and worry about doing damage. Through diverse journeys, most participants reported significant shifts at follow-up. 'Less protective' movement and postural strategies ('conscious non-protection') helped reduce pain, fear, and worry, positively changing participants beliefs. Most returned to automatic, normal, and fearless movements and postures ('non-conscious non-protection'), forgetting about their LBP. The majority reconceptualised movement and posture as a therapeutic recovery strategy rather than a threatening activity. Faster, greater amplitude, more relaxed spinal kinematics and EMG accompanied positive changes in self-report factors. For some, less protection still required attention, while one participant reported no meaningful shift, remaining protective. These data offer a framework for understanding conceptualisations about movement and posture during the process of recovery from persistent, disabling non-specific LBP, questioning traditional 'protective' movement and postural advice.

Keywords: Low back pain; movement; posture; biomechanics; psychologically informed physiotherapy; mixed methods

6.2 Introduction

Low back pain (LBP) is the most disabling health condition globally (Buchbinder et al., 2020). It's costly (Dagenais et al., 2008; Deloitte, 2019; Ma et al., 2014), and disability levels continue to escalate (Dieleman et al., 2020; Hartvigsen et al., 2018). Numerous biopsychosocial factors are known to contribute to persistent LBP, with psychosocial factors consistently shown to be important (Chen et al., 2018; Maher et al., 2017; O'Sullivan et al., 2016; O'Sullivan et al., 2018; Pincus et al., 2002). 'Correct' movement and 'good' posture are often considered important physical factors for LBP, by society (Caneiro et al., 2018; Darlow, Perry, Stanley, et al., 2014), people experiencing LBP (Darlow et al., 2015; Darlow et al., 2013; Hush et al., 2009; Lin et al., 2013), and many clinical disciplines (Karayannis et al., 2016; Sahrmann, 2021; Spoto & Collins, 2008; Widerström et al., 2021). But the relevance of movement and posture as LBP improves from individuals' perspectives remains unclear.

Descriptions of restricted, limited, stiff, tense or feared movements and postures are common among qualitative studies of LBP (Bunzli, Smith, et al., 2016; Oosterhof et al., 2014; Pugh & Williams, 2014; Snelgrove et al., 2013) and supported by quantitative findings of more rigid and protective movement patterns in people with LBP compared to those without (Geisser et al., 2005; Laird et al., 2014; Laird et al., 2019). These patterns appear to be underpinned by beliefs of damaged or broken spinal structures and fear of further damage or functional loss during painful activities (Bunzli et al., 2017; Bunzli, Smith, et al., 2016; Bunzli, Smith, Schütze, et al., 2015; Bunzli, Smith, Watkins, et al., 2015; Oosterhof et al., 2014; Setchell et al., 2017; Snelgrove et al., 2013). However, changes in rigid and protective movement patterns appear unrelated to improved LBP unless individual heterogeneity is accommodated (Laird et al., 2012; Steiger et al., 2012; Wernli, O'Sullivan, et al., 2020; Wernli, Tan, et al., 2020; Wernli et al., 2021 (in press)). When related to LBP improvement, it seems that movement and posture consistently become less protective (increased spinal range, speed, relaxation, and slumping) (Wernli, O'Sullivan, et al., 2020; Wernli, Tan, et al., 2020; Wernli et al., 2021 (in press)), but how people *conceptualise* this link remains largely unknown.

People with LBP conceptualise recovery as a complex and highly individualised process (Hush et al., 2009). A meta-ethnographic study of 195 qualitative studies exploring recovery from persistent pain highlighted the empowering influence of validation (of pain and as a person) and reconnection (with themselves and the world) that helped people envisage a future but did not specifically identify perceptions about movement or posture (Toye et al., 2021). There is some indication that changes in movement and posture may be relevant in the recovery from LBP. Qualitative quotes indirectly identify the importance of ‘moving freely’, ‘feeling supple’, and producing more ‘efficient, effective, relaxed, and comfortable’ movements and postures during recovery (Hush et al., 2009; Pugh & Williams, 2014), but this is under-researched.

Psychological factors, in addition to influencing LBP outcomes (Pincus et al., 2002), also influence movement and posture. More negative factors (for example, increased fear of movement or pain catastrophising) showed consistent, albeit weak, associations with more rigid and protective spinal movement in a recent meta-analysis (Christe, Crombez, et al., 2021). However, more research using “specific and individualised measures of psychological factors, pain intensity, and spinal motor behaviour” was recommended (Christe, Crombez, et al., 2021)(p.683).

The call for individualised assessment aligns with recent calls for person-centred care (Borsook & Kalso, 2013; Kerry et al., 2012; Lillie et al., 2011; Lin et al., 2020). One individualised approach showing promise for persistent, disabling LBP is Cognitive Functional Therapy (CFT). CFT is a physiotherapy-led psychologically-informed approach that targets unhelpful pain cognitions, emotions and behaviours (including movement and posture) (O’Sullivan et al., 2018). It has shown clinically important, sustained reductions in pain and disability (O’Keeffe et al., 2019; O’Sullivan et al., 2015; Ussing et al., 2020; Vibe Fersum et al., 2013; Vibe Fersum et al., 2019).

Rigorous replicated single-case, mixed method designs that can readily accommodate heterogeneity provide viable options for research from a person-specific, individualised perspective (Kerry et al., 2012; Kratochwill et al., 2012; Lillie et al., 2011; Toye et al., 2013). They can yield rich, comprehensive and valid clinical findings (Borsook & Kalso, 2013; Fetters & Freshwater, 2015; Lillie et al., 2011; Queirós et al., 2017). Using this methodology, we aimed to:

i) Understand how people with persistent, disabling LBP c*onceptualise* relationships between movement, posture, psychological factors (pain-related cognitions and emotions), pain or activity limitation, and how this conceptualisation changes following CFT intervention.

ii) Explore how quantitative changes in movement, posture, psychosocial factors, pain, and activity limitation integrate with this conceptualisation.

6.3 Methods

6.3.1 Design

We used a pre-post convergent mixed methods design incorporating both qualitative and quantitative approaches in the context of an existing replicated single-case design study. The existing study comprised of a five-week baseline phase, a 12-week CFT intervention phase, and a five-week follow-up phase (Wernli, O'Sullivan, et al., 2020). Qualitative data were collected through semi-structured, in-depth interviews before (baseline) and after (follow-up) the 12-week intervention, allowing the participants' perspectives, voices, and stories to be heard. We reported qualitative methods and findings in accordance with the COREQ-32 checklist (Tong et al., 2007). Online surveys collected quantitative questionnaire data at baseline and follow-up time points, while wireless, wearable sensors collected movement and postural data weekly for five weeks before and after the intervention (Wernli, O'Sullivan, et al., 2020). We were interested in how conceptualisations about movement and posture integrate with quantitative changes in clinical outcome. As we were not interested in treatment efficacy, it is not pertinent to randomise the baseline (such as in a single-case experimental design – SCED) (Kratochwill et al., 2012; Lobo et al., 2017; Tate, Perdices, Rosenkoetter, McDonald, et al., 2016). This study therefore represents a pre-post single-case study design replicated in 12 people.

We registered the study with the Australian and New Zealand Clinical Trials Registry (ACTRN12619001133123). We used the Checklist of Mixed Methods Elements, Mixed Methods Structure Guide, and the Mixed Methods Appraisal Tool to prepare this manuscript (Fetters & Freshwater, 2015; Fetters & Molina-Azorin, 2019; Hong et al., 2018).

6.3.2 Participants

We recruited twelve people with persisting (>3 months), disabling (≥5 on the 23-item Roland Morris Disability Questionnaire (RMDQ)), non-specific LBP who met the eligibility criteria (Box 6.1). Participants were recruited through social media, referrals from primary care practitioners, and word of mouth. Thirty-one people expressed interest with 19 people excluded because they did not meet the eligibility criteria. Reasons for exclusion included: planned leave of absence greater than two consecutive weeks (n = 5), body mass index >30 kg/m^2 (n = 5), RMDQ not ≥5 (n=4), trying to get pregnant (n = 1), no reason given (n = 4).

Box 6.1. Selection criteria

Inclusion criteria	Exclusion criteria

Adults aged 18 years or older
Primary complaint of LBP (between T12 and gluteal folds)
    Persistent (≥3 months duration)
    Disabling (≥5 on RMDQ)(Patrick et al., 1995)
    Non-trivial (≥3/10 across three 11-point Numerical Rating Scales identifying current, average and worst pain over the last week)(Manniche et al., 1994)
Pain provoked by movements or postures
	Dominant leg pain
	Diagnosis of LBP related to specific pathologies (infection, cancer, inflammatory disorders, fracture, radicular pain with neurological deficit)
	Pregnancy
	Inability to adequately speak or understand English
	Body Mass Index >30 kg/m^2 (to limit validity concerns about body surface-based measures in overweight or obese individuals)
	Nondisabling LBP (mean baseline Patient-Specific Functional Scale (PSFS) score <3/10 for two consecutive weeks)
	Planned leave of absence greater than two consecutive weeks throughout the 22-week study period (due to the frequent and intensive measures)

6.3.3 Setting

The study occurred in metropolitan Perth, Western Australia, in two waves (each 22-weeks) of six people between January and December of 2018. We collected qualitative and quantitative data at a primary care musculoskeletal physiotherapy practice (also the location of the intervention) or the participant's home. The Curtin University Human Research Ethics Committee approved the study (approval number HRE2017-0706), and each participant provided written informed consent.

6.3.4 Intervention

All patients underwent a 12-week, individualised, physiotherapy-led CFT intervention. Following the exclusion of specific causes of LBP, CFT targets the modifiable cognitions, emotions, movements, postures, and lifestyle factors identified to contribute to an individual's ongoing pain and activity limitation (O'Sullivan et al., 2018). CFT has shown clinically significant and sustained improvements in pain and function (O'Sullivan et al., 2015; Ussing et al., 2020; Vibe Fersum et al., 2013; Vibe Fersum et al., 2019) and is often accompanied by changes in the way people conceptualise their pain (Bunzli, McEvoy, et al., 2016).

Four specially trained physiotherapists provided up to 10 sessions of funded CFT depending on the participants' clinical course. The physiotherapists had undergone competency assessment by the developer of CFT (POS). To ensure treatment fidelity, POS observed the initial session and maintained regular contact with the treating physiotherapists during the intervention. The initial intervention session was 60 minutes, while subsequent sessions were 30-45 minutes.

6.3.5 Procedures

The data collection and analysis procedures for the convergent mixed methods design are presented in **Figure 1.**

INSERT FIGURE 1 HERE

6.3.5.1 Qualitative component procedures

Interpretive description guided the mode of inquiry for the qualitative component of this study. This approach integrates the individual experiences of the person experiencing LBP with the research teams' expertise of the condition to form credible, rigorous, and valid knowledge (Thorne et al., 1997; Thorne et al., 2004).

6.3.5.1.1 Researchers

The researchers comprised of musculoskeletal and cardiopulmonary physiotherapists and a biomechanist, all with experience in qualitative and quantitative methods. All authors have clinical and research interests in the biopsychosocial understanding of health conditions.

6.3.5.1.2 Data collection

One author (KW, BSc, male) conducted one-on-one, face-to-face, semi-structured, in-depth interviews. They occurred primarily at the participant's homes or on occasion at the physiotherapy practice or the participants' workplace. Aside from P3, the interviewer was not previously known to the participants. The participants were aware the researcher was a practicing physiotherapist completing a PhD. The interviewer did not provide the intervention. All interviews were recorded on a digital voice recorder with the participants' permission. Questions were open-ended and centred around exploring the participants' experiences, beliefs, and emotions relating to movement and posture, particularly how movement and posture related to their LBP experience. Specific movements and postures that participants reported as problematic were explored under the common-sense model of illness (cognitions, emotions, actions, and appraisals related to problematic movements and postures, and their LBP) (Leventhal et al., 2016). The interviewer gave prompts and space to explore meaning and allow divergence into relevant topics. Pertinent quotes from each participants' baseline interview were repeated at their follow-up interview to stimulate reflective discussion and explore meaning (data-prompted questions) (Kwasnicka et al., 2015). Example interview questions can be found in **Appendix 1.**

In addition to experiencing and observing several clinical encounters with the target population, the interviewer had conducted multiple pilot interviews, which were reviewed by senior members of the research team, including those with expertise in qualitative methodology. Further, the pre-interview conversation included verbally revisiting the consent for the interview to occur and be recorded. Additionally, the interviewer clarified that his role was as an interviewer aiming to hear the participants' voices without prejudice, not as a physiotherapist. That conversation also included prompts for the participants to speak honestly and not try to say what they thought the interviewer wanted to hear. This reflexivity practice also helped the researcher ensure his lens remained as an investigative interviewer rather than a physiotherapist.

6.3.5.1.3 Data analysis

Recorded interviews were transcribed verbatim and uploaded to MAXQDA (VERBI Software, 2019, Berlin, Germany) to facilitate analysis. We did not return transcripts to participants, nor did participants provide feedback on the findings. For each interview, one author (KW) listened to the interview in its entirety while making memos throughout the transcript. Then, as per Thorne et al. (1997) (Thorne et al., 1997), data that related to the question of: "how does this person conceptualise the relationship between movement, posture, and their LBP?" were classified into the categories reflecting an adapted common-sense model (see 'Category' column in Box 6.2**)**. Inductive, open coding methods were then used to analyse raw data from each category (Thorne et al., 1997). For example, under the 'Lived experience' category, codes such as: "feeling stiff/restricted/seized up" and "moving freely/with flexibility" were identified. Frequent meetings (approximately three per month) among the research group, discussions among peers, as well as reflective memos kept by the lead author enhanced reflexivity throughout the data analysis process.

Box 6.2. The identification of themes from inductive coding

Category	Sub-categories	Salient codes
Lived experience	Movement/posture	Feeling stiff/restricted/seized up More movement Moving freely/with flexibility Change in movement/posture
	Functional Gain MPs that improve pain MPs that worsen pain	
Cognitions	Confusion/uncertainty	About condition About link between pain and movement
	About body/structure	Damaged/irritated structures/biology Spine out of position/alignment Other body regions relating to LBP
	About pain	Pain science Meaning of pain with movement/postures
	About MPs	MPs as negative (cause, pain anticipation) MPs as positive (MPs as recovery/management strategies)
	Societal/HCP MP messages	MP rules (correct/incorrect, good/bad, right/wrong) Core exercises Lifestyle (e.g., sedentary)
Emotions	Fear	Of movement Of damage Of pain Of functional consequences Of future Less fear/fearless
	Anxiety/worry	Over condition, future, or consequences
	Depression/low mood/sadness	At functional loss/loss of independence/identity
	Frustration/annoyance	Diagnostic uncertainty 'Too young' to have a bad back
	Happy/hopeful	With functional gain Hope for future
Actions	Protective, cautious or careful MPs	Due to not wanting to experience pain/functional loss Due to fear of damage/vulnerable structures Tension of muscles (linked to pain or psychological state) Fidgeting/moving around
	Avoidance of MPs	Due to not wanting to experience pain/functional loss Due to fear of damage
	Management strategies	Relaxing/reducing muscle tension Breathing

		Not protecting
Appraisals	Conscious/nonconscious MPs	Conscious Nonconscious, no longer aware/cognisant
	Confidence	With MPs With managing condition
	New insights	Into usefulness (or not) of previous MP strategies
	Clear demonstration	
	Experiential learning	Of link between MPs
	Individualised education	From trusted healthcare professional Supported with scientific evidence
	No change	In MPs In pain/AL Not sustained

MP – Movement and posture, AL – Activity limitation

Three authors (KW, AS, POS) then independently performed inductive open coding on three participants' pre- and post-transcripts (six transcripts in total) to form a codebook. Coded transcripts were compared amongst these three authors over several meetings to reflect on how each researcher coded the data, made assumptions, or may have overlooked aspects of the data (Braun & Clarke, 2020). Additionally, a fourth researcher (FC) outside of the research group and with limited exposure to CFT or the common-sense model coded the transcripts of three participants as a method of peer review and to provide additional perspectives.

The codebook was refined during the process of coding the subsequent four participants, after which no new codes or themes were identified (i.e., saturation occurred after seven participants, with the remaining five participants validating the codebook).

Following open coding, five researchers (KW, POS, AS, AC, PK) then compiled the data under each category for the three participants that were cross-coded (**Appendix 2**) and identified salient intra-person themes for these participants. One researcher (KW) then completed intra-person analysis for the remaining nine participants. Two authors (KW and AS) then discussed any patterns between participants (inter-subject analysis) and identified themes, which were then discussed amongst the research group. We explored negative or divergent cases and codes to establish further understanding.

6.3.5.2 Quantitative component procedures

6.3.5.2.1 Data collection

6.3.5.2.1.1 Self-report questionnaires

We used the Qualtrics platform for the online questionnaire. The participants completed the questionnaire in their own time using a mobile device or computer. The following outcome measures were collected on all participants before and after the 12-week CFT intervention:

- Pain (collected weekly during baseline and follow-up period then averaged to identify a single pre- and post-measure):
    - Intensity - Tri-Numerical Rating Scale (NRS) (mean of current, average over last week, worst over last week on 0-10 NRS) (Manniche et al., 1994)
    - Pain interference (0-10 NRS) (Dionne et al., 2008)
    - Pain bothersomeness (0-10 NRS) (Dunn & Croft, 2005)
- Pain-related activity limitation:
    - Roland Morris Disability Questionnaire (RMDQ) (23 item) (Patrick et al., 1995) - measured at the start and end of 5-week baseline and then averaged for baseline value, measured once at the beginning of follow-up
    - Patient-Specific Functional Scale (PSFS) (Westaway et al., 1998) (collected weekly during baseline and follow-up period then averaged to identify a single pre- and post-measure)
- Pain-related cognitions (measured at the start and end of 5-week baseline and then averaged for baseline value, measured once at the beginning of follow-up unless otherwise indicated):
    - Pain self-efficacy – Pain Self Efficacy Questionnaire (PSEQ) (Nicholas, 2007)
    - Pain catastrophising – The Pain Catastrophizing Scale (PCS) (Sullivan et al., 1995)

    - Body perception – Fremantle Back Awareness Questionnaire (Fre-BAQ) (Wand et al., 2014)
    - Pain controllability - 3 item questionnaire adapted from Jensen & Karoly (1991) (Jensen & Karoly, 1991) (collected weekly during baseline and follow-up period then averaged to identify a single pre- and post-measure)
    - Back pain beliefs – Back Pain Attitudes Questionnaire (Back-PAQ) (Darlow, Perry, Mathieson, et al., 2014)
    - Trust in back – Single item answering, 'I trust my back' (0 = no trust, 10 = complete trust) (collected weekly during baseline and follow-up period then averaged to identify a single pre- and post-measure)
- Pain-related emotion (measured at the start and end of 5-week baseline and then averaged for baseline value, measured once at the beginning of follow-up):
    - Fear of Movement – Tampa Scale of Kinesiophobia (TSK) (Swinkels-Meewisse et al., 2003).

The short form Örebro Musculoskeletal Pain Screening Questionnaire was also collected at the end of the baseline phase (Linton et al., 2011). While self-report questionnaires were administered during the intervention period, these were not included in the current analysis in order for the collection periods to align with the qualitative interviews. This allowed better integration between the qualitative and quantitative findings. Further, we chose to collect the self-report questionnaires and the movement assessment sessions at weekly intervals (as opposed to daily) for a number of reasons. Firstly, the completion of the self-report questionnaires took approximately 5-10 minutes, and the movement assessment sessions took approximately 30 minutes to complete, so it would have been impractical and burdensome for participants to complete the questionnaires and have to attend the clinic daily for the movement assessment. As we were interested in relationships between conceptualisations, movement, posture, pain, activity limitation, and psychological factors, having alignment between the frequency of data collection was deemed important. Secondly, asking daily questions about pain, activity limitation, and other pain-related variables may inadvertently increase pain vigilance or a focus on the impact of pain. So, weekly measures were chosen to find a balance between participant burden, capture relevant measures at similar timepoints, and minimise focus on pain.

6.3.5.2.1.2 Measurement of movement and posture

The participants each nominated three movements or postures that they found most problematic on the PSFS. These were measured by wearable sensors (V5 ViMove hardware and software, DorsaVi, Melbourne, Australia) on a weekly basis at the physiotherapy clinic during the 5-week baseline and 5-week follow-up period. A researcher (KW) blind to clinical outcome (questionnaire) data and not involved with the intervention collected the movement and posture data. Sagittal plane kinematics were collected by two wireless inertial measurement units (placed over the spinous process of T12 and S2) sampling at 20Hz. Lumbar muscle activity was collected by two wireless surface electromyographic (EMG) sensors (placed two centimetres on either side of the L3 spinous process following light abrasion and cleaning of the skin) sampling at 300Hz. We collected three repetitions of each nominated movement and 15 seconds of unsupported, self-selected postures. This ecologically valid clinical sensor system facilitated the frequent measures and has demonstrated clinically acceptable agreement compared to the Vicon motion capture system, the industry-standard (Mjosund et al., 2017). Further information about the sensor specifications, normalisation, calibration, and processing procedures are detailed in Wernli et al. (2020) (Wernli, O’Sullivan, et al., 2020).

6.3.5.2.2 Data analysis

Questionnaire data were collated for each participant. As we had a variable number of baseline self-report outcome measures (for example two RMDQ and TSK, but five pain intensity, pain control, and trust), we chose to average within construct these data to form a singular ‘pre’ value. Because our research questions were about understanding how conceptualisations about movement or posture change and how these integrate with quantitative changes (we were not interested in treatment efficacy), whether self-report outcomes were already improving during the baseline period was not pertinent in this context. Similarly, where we had multiple measures of the same construct during the follow-up period, these were averaged to form a single ‘post’ value. We analysed movement and postural data as per the previously published replicated single-case design (Wernli, O’Sullivan, et al., 2020) and calculated a mean value of relevant movement and postural data for the 5-week baseline and 5-week follow-up period, forming a single pre- and post-value.

6.3.5.3 Integration

We integrated qualitative and quantitative findings using a joint display to draw meta-inferences across the two types of data. This integration method is in line with the premise that the strength of a mixed-methods study lies in the integration of the two data types, garnering a richer understanding than the data types in isolation (Fetters & Freshwater, 2015).

6.3.6 Data transparency

For qualitative data, deidentified direct quotes are embedded in the results of this manuscript with additional supporting quotes presented in **Appendix 4.** Full transcripts are not presented to protect the privacy of the individuals as they contain potentially identifiable information. De-identified full transcripts are available from the lead author at reasonable request. For quantitative data, all baseline and follow-up measures are reported for each participant in the results section or **Appendix 3.** Raw data used to calculate the mean of each participants' baseline and follow-up phase are available from the lead author at reasonable request.

6.4 Results

All twelve participants completed the study, and their de-identified demographic and clinical characteristics are presented in **Table 1** (with detailed descriptions provided in **Appendix 3**). Their median (range) baseline demographics were; age: 39 years (22-76), duration of LBP: just over four years (11 months to 17 years), RMDQ score: 17.5/23 (12-22), and Örebro Musculoskeletal Pain Questionnaire short form: 56.5/100 (41-79), with 10/12 participants scoring above the cut-off (>50) for high risk of future disability (Linton et al., 2011). The participants reported significant previous engagement with the healthcare system, consulting with multiple healthcare professionals, including physiotherapists, chiropractors, naturopaths, osteopaths, general practitioners, radiologists, or orthopaedic surgeons (participant 12 had a spinal fusion as part of a workers compensation claim). Many participants reported taking significant time (up to 4 years) off work due to their LBP and frequent medication use (including 4/12 reportedly using opioids). Most (7/12) reported other medical co-morbidities (such as atherosclerosis, reflux, bronchiectasis, anxiety, depression, post-traumatic stress disorder, migraines, elevated cholesterol, tinnitus, lupus, hyperthyroidism) and family histories of LBP (7/12). Qualitative interviews lasted approximately 60 minutes (30-100 minutes), and all participants completed all qualitative interviews. All data required for the quantitative analysis were available. No participant dropped out of the study or chose to terminate an interview. Themes and supporting quotes are presented in text (with additional supporting quotes presented in **Appendix 4**), while quantitative and integrated findings are presented in **Table 2.**

INSERT TABLE 1 HERE

6.4.1 Qualitative findings

Findings from the qualitative analysis revealed distinct themes of protection during the baseline interviews and non-protection, or less protection, during the follow-up interviews. Reports from some participants highlighting a progression from conscious non-protective movement and postural patterns to automatic and thoughtless non-protective patterns led to the generation of conscious non-protection and nonconscious non-protection themes. This journey from protection to non-protection is presented in **Figure 2**.

INSERT FIGURE 2 HERE

6.4.1.1 Baseline interviews

6.4.1.1.1 Nonconscious protection

6.4.1.1.1.1 Experiences and actions

During the baseline interviews, all participants conveyed varied lived experiences of their back feeling 'stiff, tight, tense, spasming, rigid, and locked or seized up' during painful movements and postures:

"(My movement) gets more rigid. It slows down, and it just seizes up really… I feel tightness. For sure. Pretty much all the time… it's kind of like, just like a pulling to the centre of where the injury is" – P2 baseline

"The lower backache (goes into spasm). It feels like, um, yeh it just can't move, so it goes into this spasm. And this pain just shoots through my, um, legs" – P8 baseline

With many participants reporting less and slower spinal movement:

"(My movement is) a lot slower and a lot more grimacing. You take the face from two years ago, it would be quite the opposite. Because it all aches" – P1 baseline

6.4.1.1.1.2 Cognitions

Most participants attributed this ‘stiffness’ to ‘damage’, an ‘injury’, or ‘something being structurally wrong’ with their back:

> *“(It’s stiff because) I mean I’m no doctor, but looking at the x-rays of my back, you can see the vertebrates quite close together” – P9 baseline*

Often also attributing their spinal condition to ‘poor posture’, ‘incorrect movement or lifting techniques’, or a ‘weak core’:

> *“I think it’s to do with my posture. I try to sit up tall and straighter. I slouch too often, and my wife will remind me” – P5 baseline*

> *“I probably had pretty bad core strength up until 42, so that’s obviously not helping… Now that I’ve got a bit of an idea about how the back works, your core muscles are going to protect your back to an extent. And because I haven’t ever worked on core strength, I’ve been lifting heavy billboard skins for the past 15 years and I was a plumber and a labourer before that. I probably put a lot of strain on it I guess over the years” – P9 baseline*

Most of the structural damage beliefs were informed by imaging, encounters with healthcare professionals, common societal messaging, or researching their condition on the internet:

> *“I had a scan, and it said my L-1 L- something is bulging, and I've got a bulging disc and something. I don't know what all that is anyway” – P3 baseline*

> *“The MRI report said, 'disc protrusion'… I picture my disc being pressed out of the back of my, back of my spine” – P4 baseline*

Most participants also expressed significant uncertainty around the cause of their pain, what treatment was required, and why specific movements and postures aggravated or eased their pain:

> *“And then from standing too much, I actually don't, I don't know why it hurts when I stand too much” – P4 baseline*

> *“I’m not sure. I don't know why strengthening the core is making it so much worse.” – P6 baseline*

Some participants uncertainty was also exacerbated by conflicting messages from healthcare professionals:

> *“Some say I've got weak, a weak core, so I need to do Pilates sort of strengthening, but others say I've got a strong core because I can deadlift*

heavy. So yeah, sometimes I'll just go and hear what I want to hear and say, Oh, 'I've got a strong core, I don't need to do anything'." – P4 baseline

6.4.1.1.1.3 Emotions

The highly unpleasant and often intense spasming and stiffness induced a strong feeling of fear in many participants:

"But yeah, that locking up feeling is scary, not being able to do anything with your body" – P11 baseline

As well as significant worry; about the pain, loss of function, and future:

"(The persistent LBP) it worries me a lot because I don't want to be a crippled old person…I'd rather do things with my kids. I'm too young" – P7 baseline

While for others, frustration was the ensuing dominant emotion:

"Frustration with a big F… because I don't want to put up with this… Here we go again, it's annoying me, and I can't do what I'd like to do" – P1 baseline

6.4.1.1.2 Conscious protection

6.4.1.1.2.1 Experiences and actions

While participants detailed lived *experiences* of feeling 'stiff, tight, and restricted' during the baseline interviews, they also described *consciously* doing things to protect their back. For example, all participants reported that since the onset of their back pain, they were careful and cautious with their movements and postures:

"I have to be careful about everything I do and how I do everything" – P7 baseline

"I'm just always conscious of everything I do… At work, I'm having to think about everything I do all day long" – P9 baseline

With many now attempting to follow rules that they believed were the right thing to do for their back based on encounters with healthcare professionals or common societal knowledge. Common rules were about posture:

"(I protect my back) by not slouching as much, standing up and sort of protecting myself more of what I do. Cautious" – P3 baseline

"They (the previous physiotherapists) said not to slouch… don't sit lounging on a lounge. Don't put your legs up… I think it was laying on your stomach is bad for it… just watch yourself when your lifting… bend your knees… so that you're not arching (bending) your back over." - P2 baseline

Other rules were about movement and lifting technique:

“I think I’d be hesitant now... I guess when I lift the kids… I wrap my arms around them and bend my knees and try and lift them with a straight back, I'm not just bending and pick them up” – P9 baseline

While rules relating to ‘core’ muscles were also common:

“I'll try to engage- like sort of tense my stomach and engage, engage my core as best I can. I feel like that's an area that I'm not particularly good at, but um, all I know in terms of engaging my core, I just pretty much try to tense everything and make sure everything's tight.” – P4 baseline

“I pull my abs in to try to keep my core on, keep my posture upright” – P6 baseline

These conscious protective behaviours contrasted with how the participants reflected on how they moved and postured themselves before the onset of their symptoms when they didn’t have pain or concerns about their back.

“Oh well I didn't worry (about picking the shopping bags up) three years ago. I'd just do it. Now I take caution not to do it. Just because I don't want to end up being on my bed for the rest of the day or the next day” – P3 baseline

“I used to be pretty... like I would just do it, no fear. I used to do backflips into the pool with no fear. I used to just be happy to jump up and down and climb trees, jump off the roof or I don't know, just like kids do. Um, I was really into some martial arts films and doing like those kung-fu kicks and stuff like that. Yeah, I'd have, I was fearless that time… So yeah, in terms of picking something up back then. Yeah, no fear and didn't give it a second thought.” – P4 baseline

And contradicted their experiences of less pain when they were more relaxed:

“(I think my pain was better after the massage) because I'm relaxed in my bones and muscles, I suppose. I was less tense maybe” – P3 baseline

“(The massage) almost like, it frees up that area a bit the, the 'infected area', it's. Yeah. It doesn't take the pain away completely one hundred percent, no. I would say I probably get a good um, a good 50 percent relief from the pain and the tightness” – P8 baseline

While the ‘conscious protection’ during the baseline interviews manifested in *protective* movement and postural patterns, it was also associated with explicit *avoidance* of perceived threatening tasks:

“Yeah (I avoid bending altogether), I squat or yeah, use my little grabby thing… I avoid a lot of things because it hurts too much.“ – P7 baseline

“Yeah (I protect my back), just in as much as I try to avoid doing anything that might damage or aggravate it.” – P12 baseline

During the baseline interviews, most participants conveyed a sense of short-term control over their pain by utilising these protective and avoidance behaviours. Still, they expressed a distinct gap between how much control they had now and how much control they’d like:

“In a perfect world, if I could just do the right things all day long, I could potentially have control over it… I can minimise my pain by stretching and exercising every morning; I would say that gives me a fair bit of control… but no, god no, nowhere near (the amount of control I want).” – P9 baseline

“So, it has control, really, because I obey the pain. But therefore, since I have strategies to control the pain (sit up straight, avoid painful tasks), I do have some influence over it too. Yeah. So I think it's got a lot of power over me, but I've got a little bit of a way of appeasing it.” – P12 baseline

While some reported little control over their pain:

“No control at all (in terms of predicting my back pain). None. That’s the frustration.” – P5 baseline

“From 1 to 10, I’d probably go 8-no control… (it feels) terrible.” – P8 baseline

6.4.1.1.2.2 Cognitions

In addition to the strong beliefs about the contribution of current ‘poor’ posture and movement contributing to their back condition, many participants also believed historically ‘incorrect’ movement and postural behaviours were contributors to their current back troubles:

“It just obviously it happened because I must've been doing something wrong over the years and then eventually it just said nup see ya later and went.” – P2 baseline

“Even though I get up and walk around once an hour, I can be really at my computer for 12 hours. And if you do that for your whole life, you know for years, decades then I think that you, unless you happen to have a very good lumbar support chair or lumbar support or there, that's probably decades of slouching.” – P12 baseline

Further, many participants believed it was more important to follow these postural rules that ‘protect’ their spine, despite these postures sometimes resulting in more pain:

“(Sitting upright) makes it worse, but I just thought I'm meant to keep my posture upright.” – P6 baseline

In addition to the beliefs about the perceived negative impacts of 'poor' posture, beliefs of a fragile and vulnerable spine were prominent amongst the participants. This perceived fragility and vulnerability was driven mainly by significant pain responses following minor tasks:

"So, I just think, one little wrong tilt and you're broken… I've been very careful because constant back pain reminds you to be careful, which is good. But even a little, even if I look at my back wrong, it reacts." – P12 baseline

"You are so fragile to doing little activities." – P11 baseline

But also secondary to advice from healthcare professionals:

"I had an MRI and showed the results to the doctor, and the doctor basically said you should stop doing any sort of physical activity, and swimming is all I should do." – P4 baseline

6.4.1.1.2.3 Emotions

The constant conscious protection (both cognitively and behaviourally) resulted in a heightened state of pain vigilance associated with negative emotions. These negative emotions were related to the impending further damage to their structures, as well as the potential functional consequences, the unpleasantness of pain exacerbations, and the future. These negative emotions included fear:

"That's ('slipped disc') pretty much my main fear because that's the, when I talked to other people with back pain, the slip disc disorder is the worst." – P4 baseline

And worry, particularly about the future:

"If I'm like this at 50, what am I going to be like at 70. To me I worry because it's, yeah, I need to be able to move. If I can't move now, in 10 years' time, you know, what am I going to be in a wheelchair? It freaks me out it honestly does." – P8 baseline

While participants also reported negative emotions such as frustration and annoyance:

"I think it annoys me to a point where I get kind of cranky and. Oh, I got to be careful because I am a person that suffers from depression. So that can kick in, and it can just be snowballing to where I don't want it to go; in a space where I just go, I can't do this anymore. I'm not doing it." – P8 baseline

6.4.1.2 Follow-up Interviews

6.4.1.2.1 Residual nonconscious protection

While rare, lived experiences of bothersome tension, tightness, and stiffness were still occasionally reported during the follow-up interview:

"My muscles stiff, I wouldn't say my muscles hurt, but I don't quite know why, whether that's inflammation or whether they're being held too tight." – P1 follow-up

For participant one, a nonconscious tendency to tense up remained:

"Without thinking, I probably tense up again. But I can't spend my whole life relaxed." – P1 follow-up

But most reported these experiences as fleeting and quickly modifiable using strategies learnt during the intervention:

"There's been a few times where my back's gone a bit stiff and funny. But work through it the way you guys told me to, stretching and on the bike and all that, and just keep moving and all good." – P2 follow-up

6.4.1.2.2 Reflections on conscious protection

During the follow-up interviews after the 12-week intervention period, 11/12 participants no longer discussed protecting their back, reporting they now perceived their previous protective patterns to be unhelpful:

"The more I brace, the more tension there is and then there's more pain… I guess subconsciously, unintentionally, when you're hurt, you brace against the pain, you tighten things up to protect yourself." – P6 follow-up

"I sort of maintained that position or stiff movement to protect what I thought was damaged. But it's not. If anything, I think I just filled the so-called 'injury' by continuing that protection mode of movement – P8 follow-up

Participant one found relaxing difficult and maintained a protective movement and postural pattern. She reported a profound dis-ease with relaxing - despite it potentially feeling better physically, it felt 'un-natural' and worse psychologically:

"I can't do it all day. As soon as I'm relaxed and find some little bit of relief and then continue what I'm doing, you probably don't continue in the same relaxed mode because you're concentrating on what you're doing, and you might relapse into more tightness of muscle… It's difficult to concentrate on the relaxation, and to me, it doesn't feel natural… Psychologically, no (it doesn't feel better). See, that's the problem. It's so ingrained - psychologically it's not right, maybe physically it's better." – P1 follow-up

Participant one continued to report experiences of muscle spasm that she understood to relate to persisting damage, and therefore maintained a cautious, protective movement and postural pattern:

> *"Coming up (from bending), the back is just spasming across… I always feel that if I make a wrong move, it's going to go out of traction… it feels like somethings going to get caught… I'm probably careful to not go sideways of off the centre too much; I'm not game enough to try (coming up sideways). I've got enough pain without trying that one out. So, I come up without taking too many risks say. Just coming up straight". – P1 follow-up*

She didn't have an experience that made sense to her and retained beliefs of structural damage:

> *"To me, it's just that I've got, I've done some damage there… And to just do the normal things, I'm at a disadvantage because my back doesn't like it anymore, and until it's repaired, it's not going to give me less pain." – P1 follow-up*

Beliefs that were still accompanied with frustration, although perhaps less and somewhat re-calibrated.

> *"I got to the point where I said I can't do this anymore because my back got so sore, doing all these exercises, exactly the way (the physiotherapist) had shown me. That just got too much… there's people around with bigger problems than that, so you say, 'don't complain, just carry on. It could be worse.' So, frustration comes and goes." – P1 follow-up*

6.4.1.2.3 Conscious non-protection

After the 12-week intervention, 11/12 participants reported a strong focus on moving and posturing themselves in 'less' or 'non-protective' ways.

6.4.1.2.3.1 Experiences and actions

Consciously 'relaxing' and 'breathing' during pain provoking movements and postures yielded reductions in the participant's pain:

> *"And the biggest thing I've taken out of it's just the advice with slowing down the breathing and trying to relax" – P9 follow-up*

> *"Learning to relax my back... that was yeah, I think that's the thing that really helped" – P10 follow-up*

For most, these experiences of pain reduction by consciously changing their movement and posture were powerful learnings, and often surprising, both in their simplicity and their contrast from the common societal and healthcare messages:

"I thought I was stuck with it for life. So, the fact that it's been as simple as just changing a few of my movements and, you know, looking at my sort of levels of tension… I can't believe that that was all I had to do all along, you know, that it was basically my own kind of, the onset of pain was probably caused by what I was doing, as opposed to something failing in my body." – P9 follow-up

In contrast to previous healthcare messages of 'don't move', 'protect', or 'avoid', the new clinician messages gave them permission to move normally, and it felt better:

"Doing everything opposite to the way that you're told to do it… feels better… way better" - P11 follow-up

6.4.1.2.3.2 Cognitions

Many participants now understood that doing the previously frightening and painful movements could be therapeutic:

"You keep moving, and then it's just like, it (pain and tightness) just goes away. Like you've taken an anti-inflammatory, a real good one that gets rid of it. Except you're not, you're just doing exercise; you're doing movement to keep it going. – P2 follow-up

"It's not just like 'you're injured, you can't do anything', like 'don't do anything'. It's 'you're injured, move more' kind of thing or do these exercises to make this part of you strong." – P7 follow-up

The powerful experiences of less or no pain during threatening tasks, often during behavioural experiments in the initial treatment sessions, made many participants question their previous understanding of what was causing their pain:

"But the biggest thing would have been the, the Jefferson curls (round back deadlift during the second session). Just having my worst-case scenario put in front of me, the scenario where I go, 'if I do this, a hundred percent, my back would break'. And then when you do it and you're fine, then that just, yeah, that flips your world upside down." – P4 follow-up

"What un-packed it for me was moving and realizing that it's not damaging anything. It won't damage anything." - P8 follow-up

Most of the participants no longer believed that their pain was due to 'damaged structures':

"I know that there was for, for the most part, there was really nothing wrong um, structurally, uh, the only thing wrong was my belief and my, which manifested itself into improper or what I say now is the improper movement or restricted movement." – P4 follow-up

"There was no damage…I think I just filled the 'so called' injury by continuing that protection mode of movement because I thought I was damaged." – P8 follow-up

Instead, participants perceived muscle tension as a dominant contributor to their pain:

"It was probably the presentation of the of the actual theory that we're talking about, with being tense causing my pain… Yeah, it was having that explained. I mean, that's it, it took a little while to sink in, but that was probably the pivotal thing for me." – P9 follow-up

"I now don't think that's (damage) what was causing the pain, I now think clenched muscles were causing the pain. Because they were clenched in order to protect the back, but it wasn't necessary for them to do that, they were not effective. So, they were clenching like mad, and that was hurting." – P12 follow-up

These experiences often resulted in participants no longer thinking that their body was fragile and vulnerable:

"I don't feel like I'm structurally unsound if I, if I pick up a weight and, or someone throws a weight to me, I'm not going to collapse... I'm not fragile." – P4 follow-up

Most participants were also able to make sense of their pain after the intervention, reducing their uncertainty:

"Because things actually like made sense. It was the most sense anyone had probably said to me. More than instead of just going, 'yeah we're going to give you like pain meds, or we're just going to shove needles in your back' or stuff like that. It's that the physio actually wanted to fix it and then have a long-term goal and not a short-term fix. So then yeah, the physio wants to get rid of me eventually." – P7 follow-up

"I do not find it odd at all anymore (that using the back makes it stronger). I feel that it totally makes sense." – P12 follow-up

6.4.1.2.3.3 Emotions

Experientially learning strategies to reduce their pain while engaging in previously feared and avoided tasks combined with individualised education helped participants realise they were safe to move in a non-protective manner, resulting in a reconceptualization of their pain. These experiences helped shift the previous emotions of fear, worry, frustration, and depression; to happiness, hope and confidence:

"The stuff that I was the most worried about I have done, not in bulk, but I am doing, and I don't seem to be having too many problems. So yeah, I'm still getting a little bit of pain here and there, but it's completely manageable. So, I'm not, it's not even a concern." – P9 follow-up

"Look, I feel pretty positive about it (the future). It's exciting to think that it's given me; it's almost a new lease on life. I can start, I'm starting to look at things that I had pretty much swept under the rug you know, stuff like playing tennis or golf was something, you know I might go and do it occasionally, but it was, I'd pretty much resigned to the fact that I wasn't going to play those sorts of sports anymore." – P9 follow-up

Many participants also talked about how it was their *beliefs about damage* that *accompanied* the high levels of pain that worried them, not just the high pain levels themselves:

"I don't really think too much that it (pain) worries me now because when I was damaged, it worried me." – P2 follow-up

"Well, fear of pain or really, really fear of damage I think, is what I always told myself. That I was wanting to make sure I didn't make my condition worse, to not make it worse if possible. Though I fully expected it to gradually get worse, I didn't want to accelerate that process. I was scared of getting worse and worse, until one day I wouldn't be able to stand up at all… and also information that in fact, that whole spinal region can improve, in fact, with exercise and stuff – rather than get worse or not get worse, but actually improve, that takes the fear out of things because there's an upside to everything you do then, rather than only a downside." – P12 follow-up

6.4.1.2.3.4 The importance of generalisation of behavioural learning

For the experiences of pain reduction by modifying movement and postures during the treatment sessions to be sustained, many participants expressed the importance of generalising this into their home life, strengthening their sense of control:

"I could lift more weights when I keep my back loose, and I could, I don't know, vacuum for longer. I could do dishes for longer, and if I'm sitting and I'm in pain, that's the first thing I think of, "Okay, loosening the muscles." So yeah, the postural change, it's a huge mind shift now." – P6 follow-up

"(Control?) Out of 10, probably a 10" – P8

While participant one experienced some pain reduction with conscious non-protection, she failed to experience substantially strong, meaningful, or integrated changes:

"I try and concentrate on relaxing, but it only works for a minute or so and then starts to ache again…So it's developing a completely different new habit. There is not enough change in it to really make a difference, but I can see that long term, it would be beneficial to do the methods like that (relaxing) more often than not. So, keep going. Keep going." – P1 follow-up

While the power of being able to reduce pain by 'relaxing and breathing' was obvious to most, some participants (P3, P5, P7, P9) reported that this new way of moving and posturing themselves was not automatic yet… non-protection still required conscious attention:

"When you've had that habit for a long time, very hard to break. I can do some work out the back and forget and do it the old way and suffer the consequences." – P5 follow-up

"I do everything mainly different. I walk different, I sit different. I constantly have to remind myself to do it, and it's not automatic yet. But yeah, I do a lot of things differently." – P7 follow-up

6.4.1.2.4 Nonconscious non-protection:

6.4.1.2.4.1 Experiences and actions

While some participants reported that reducing their pain by consciously modifying their movement and posture gave them a sense of control over their condition, leading to significant changes in their function, many participants (P2, P4, P6, P8, P10, P11, P12) progressed further, reporting a return to automatic and instinctive movements and postures:

"Before, it was a lot more of, there was lots of thought that went into that bend and it's like 'can I actually do this?', 'is it going to hurt?', 'just be careful'. Whereas now it's just automatic. I bend, I pick up, I come up, and that's good… I'm certainly not moving like a grandma anymore. I can move a lot faster, which is nice. It's really, really good to feel like I can move. I don't have to think about it. I don't. In fact, I think I'm at the point where I generally don't give it a lot of thought. I tend to just do." – P8 follow-up

*"(Before, I'd be) bending my knees, keeping my back straight, trying to pick up correctly, now I don't give a f**k… I don't think about it, I just do it." – P11 follow-up*

Appendix 4 (6.13.4) provides further quotes that support the inductive generation of the conscious non-protection and nonconscious non-protection themes.

6.4.1.2.4.2 Cognitions

By progressing from conscious non-protection through to nonconscious non-protection, these participants had regained automatic, fearless movement and no longer considered themselves to have a back problem:

"At first, I was trying to retrain myself to allow myself to, to arch (flex), but now I just move, however, my, um, you know, my body wants to move without fear. KW: Yeah, so it's gone from being conscious to now being back to unconscious? P4: Yep. KW: Okay. And why do you think this has changed? P4: Um, I just believe I'm fine. I believe my back is strong." – P4 follow-up

"I just feel back to where I was sort of thing (before having a back problem)." – P2 follow-up

This reconceptualisation, for most, abolished the belief that they had to protect their back or avoid painful movements that they previously believed meant damage… they regained confidence in their body:

"No, I don't feel like I need to (protect) now. I don't, well, I do what I need to do. I do the movement. I do the strength exercises." – P2

"If I am lifting them (kids) up off the ground, I'm doing it, you know, I'm doing it slightly different. I'm a lot more confident. So, I'm not; I guess when I'm doing it, I'm not bracing myself for it so badly. So definitely different." – P9 follow-up

6.4.1.2.4.3 Emotions

Like the conscious non-protection group, the dominant emotions felt in the nonconscious non-protection group were of positivity, hope, less fear, happiness, and a sense of trust:

"I think I'm managing pain a lot better. I think I've got a different outlook on my whole diagnosis I think, and that's what's really improved my outlook on it. And I suppose it helps with my mood as well as in terms of not feeling down like I've got a more positive outlook on the rest of my life, I suppose." – P11 follow-up

"I feel good. I'm happy I can; I'm not afraid anymore. I can do what I want. I can play more sport; I can lift heavier weights. Um, I don't have that fear of being injured and crippled and old and disabled. So, I've just got free reign to, to live my life how I want… I can trust it to a point where I'm not afraid to, well, yeah, I'm not afraid of my future. I'm not afraid that when I'm older I'm not going to be able to play with my kids or lift my dog or carry my wife, or like... I can do whatever." – P4 follow-up

Together, these qualitative findings highlight a significant reconceptualization of how participants view the relationship between movement, posture, and their LBP; from movement and postures being a threat and the need to protect their back to learning to not protect their back during movement and postures as a therapeutic recovery strategy.

6.4.2 Quantitative findings integrated with qualitative findings

Findings of the qualitative and quantitative components for exemplar cases from each qualitative group at follow-up (nonconscious and conscious protection, conscious non-protection, and nonconscious non-protection) are integrated using a joint display table (**Table 2)**, with the quantitative data for the remaining participants available in table and graphical (radar graphs) form in **Appendix 3.** The comparison between qualitative and quantitative findings highlights how objective biomechanical measures and self-report questionnaires frequently supported participants' perceptions about their movement and postures. There was significant diversity among participants, both in the baseline and follow-up findings and in the amount of change. For example, some participants movement speed increased, but not their range (P1), while for others, speed didn't change, but their range did (P5), and for some, both changed (P8). Additionally, P1 reported no overall change in her condition during the follow-up interview. Yet, she had a substantial reduction in her pain bothersomeness, increased her bending speed by 21°/s (a 41% increase, which may have been due to task familiarisation), and had considerable improvements in her fear of movement and pain control.

INSERT TABLE 2 HERE

6.4.2.1 Additional analysis of quantitative differences between qualitative groups

Given that there was some distinction in how participants conceptualised the link between their movement, posture, and LBP during the follow-up interview (protection, conscious non-protection, or nonconscious non-protection), we explored whether participants who progressed to *nonconscious* non-protection (n = 7) had greater changes in activity limitation, movement, and psychological factors than those who remained consciously non-protective (n = 4). Graphs suggest a pattern of larger changes for those participants who progressed to *nonconscious* non-protection than those who remained consciously non-protective (**Appendix 5).** A non-parametric test of difference in ranks of change scores between the *conscious* non-protection and *nonconscious* non-protection groups showed greater changes in pain self-efficacy ($p = 0.042$) and pain catastrophising ($p = 0.042$) in the nonconscious non-protection group. Although some other change scores appeared to be potentially discriminatory between the groups on graphical display, the differences were not significant with the small sample available (TSK-change, $p = 0.109$; BackPAQ-change, $p = 0.230$; and bending speed, $p = 0.171$). Other change scores did not show graphical or statistical evidence for differences between the groups (RMDQ-change, $p = 0.618$; FreBAQ-change, $p = 0.242$; and bending ROM-change, $p = 0.609$).

6.5 Discussion

6.5.1 Key findings

This mixed method study investigated how 12 people with persistent, disabling non-specific LBP conceptualise the relationship between movement, posture, and their back pain before and after their rehabilitation journey. Before the CFT intervention, participants reported painful, stiff, tense, and restricted movements and postures. They were vigilant to sit and stand upright, were careful and limited back movement, and would tense their trunk muscles in an attempt to control their pain and protect their back from further damage. Others used movement, posture, or activity avoidance as strategies to protect their 'damaged' back. These coping behaviours were often secondary to advice from clinicians and were associated with fear and worry about doing further harm if they moved without protection.

After the CFT intervention, most participants described conscious efforts of less protection during provocative movements and postures that led to improved pain and function. Many progressed to automatic, fearless, fluid, and normal movements and postures (nonconscious non-protection). Positive shifts in pain beliefs, reduced pain-related fear, and positive emotions were also reported. These qualitative findings were supported by changes in person-specific quantitative measures and together demonstrate a re-conceptualisation of movement and posture, from threatening, to therapeutic.

6.5.2 Protection as a response to LBP at baseline

6.5.2.1 Nonconscious protection

The lived experiences of stiff, restricted, tense movements and postures reported at baseline are consistent with research demonstrating that experimentally induced pain in the low back results in increased back muscle activity, trunk muscle co-contraction, slower and less amplitude ROM, and increased stiffness (Arendt-Nielsen et al., 1996; Dubois et al., 2011; Graven-Nielsen et al., 1997; Jacobs et al., 2011; Wong et al., 2016). This work highlights that the presence of pain itself results in motor responses impacting on movement and posture. This research is also consistent with findings from systematic reviews showing more protective kinematic and EMG features in people with LBP (Geisser et al., 2005; Laird et al., 2014). In addition to the experience of pain itself, more negative psychological factors (such as fear, catastrophising, or LBP beliefs) have been shown to be associated with more protective movement behaviours (Christe, Crombez, et al., 2021; Karayannis et al., 2013; Matheve et al., 2019; Osumi et al., 2019), even in those without LBP (Knechtle et al., 2021; Trost et al., 2012), supporting the presence of a close mind-body relationship.

6.5.2.2 Conscious protection

The strong protective movement and postural beliefs (‘keep your back straight’, ‘be careful’, ‘brace your core’, ‘sit/stand tall’) reported in this study are common among people with LBP (Darlow et al., 2015), healthcare professionals (Darlow, 2016; Darlow et al., 2013; Nolan et al., 2018; Nolan, O'Sullivan, et al., 2019) and society (Caneiro et al., 2018; Darlow, Perry, Stanley, et al., 2014; Nolan et al., 2021; Slater et al., 2019). Similarly, the underlying beliefs and worries that pain represents further damage and functional loss are also common among people with persistent pain (Bunzli, Smith, Watkins, et al., 2015; Caneiro et al., 2020; I R de Oliveira et al., 2020; Setchell et al., 2017; Stenberg et al., 2014). As well as protection, conscious avoidance was also a commonly reported coping strategy, congruent with previous studies in people with LBP (Bunzli et al., 2017; Darlow et al., 2015). Consistent with previous reports (Christe, Nzamba, et al., 2021; Darlow et al., 2015; Setchell et al., 2017), the origins of these negative beliefs and unhelpful behaviours were usually from encounters with healthcare professionals.

Despite reporting using protection and avoidance strategies to control pain, participants had high levels of pain, disability, and distress, suggesting that these were ineffective. Interestingly, during the baseline interviews, all participants described insights where more relaxed, less protective postures, in fact, reduced their pain. To our knowledge, this discrepancy between a person's belief and behavioural response to pain (i.e., *'more protective posture is important to protect my back'*) and their personal experience (i.e., *'I experience less pain when relaxed'*) has not been documented before. It highlights the powerful role that beliefs coupled with clinician advice has on behaviour, even when contradicted by experience. This dissonance raises further questions about the iatrogenic contribution to LBP-related disability (Lin et al., 2013; Loeser & Sullivan, 1995; Webster & Cifuentes, 2010).

The concept that pain may result in both nonconscious and conscious protective responses, reinforced, or amplified by negative pain-related cognitions and emotions, is consistent with a contemporary neurobiological understanding of pain (Brodal, 2017). It has been proposed that 'protective' movement and postural behaviours may in themselves be pro-nociceptive (O'Sullivan et al., 2018), potentially contributing to a cycle of pain sensitisation, distress, and disability in people with persistent, disabling LBP (Bunzli et al., 2017; Leventhal et al., 2016; Vlaeyen et al., 2016). A previous meta-analysis found consistent but only weak associations between negative psychological factors and protective movement (Christe, Crombez, et al., 2021). In that review, quantitative measures of psychological factors and movement were non-individualised, with included studies having limited ability to accommodate a person's unique pain cognitions, emotions, and functional limitations. In contrast, our study design accommodated the heterogeneity characteristic of people with persistent LBP (Maher et al., 2017).

6.5.3 Follow-up Post CFT Intervention

During the follow-up interviews after the 12-week CFT intervention, nearly all (11/12) participants described how important (and, often, surprisingly simple and effective) 'less protective' strategies (relaxation, breathing, fluid movement) were in reducing pain. The dominant movement and postural narratives during follow-up were that rather than worrying about, protecting against, or avoiding movements and postures, the participants now felt they could reduce their pain by being 'less protective' during threatening activities such as bending, lifting, sitting, or standing. In this way, non-protective movements and postures became therapeutic rather than a threat. This shift is consistent with the goals of CFT, which seeks to help people reconceptualise pain from a biopsychosocial perspective (O'Sullivan et al., 2018). Underpinned by a strong therapeutic alliance and patient validation, CFT uses guided behavioural experiments that explicitly train non-protection (i.e., diaphragmatic breathing, body relaxation, and the elimination of safety behaviours) during graded exposure to previously painful, feared, or avoided functional tasks to build self-efficacy and dispel unhelpful beliefs about the need to protect the back (O'Sullivan et al., 2018).

6.5.3.1 Persistent protection prevailed

For one participant (P1), there was no sustained or meaningful change to her presentation. Unlike the rest of the participants, P1 did not report strong experiences of pain control generalised into her everyday life. She retained damage beliefs, lacked a sense of independence, and didn't have helpful pain control strategies; all factors identified as important for recovery by previous qualitative literature (Bunzli, McEvoy, et al., 2016; Riikka Holopainen, Pirjo Vuoskoski, et al., 2020; Toye et al., 2021). In the context of our research question, she didn't report experiencing pain-relieving 'supple', 'free', and 'relaxed' movements after treatment, important aspects of recovery in people with LBP (Hush et al., 2009; Pugh & Williams, 2014).

6.5.3.2 Conscious non-protection

Like our findings, learning to consciously move in more relaxed and efficient ways instead of stiff and restricted ways has been previously reported as important for people that improve from persistent LBP (Pugh & Williams, 2014). Similarly, reconceptualising pain as; not equalling damage, being multifactorial, and retrainable, have previously been reported as important in people recovered from persistent pain (Bunzli, McEvoy, et al., 2016; Leake et al., 2021). Our frequent kinematic and EMG findings of faster, greater amplitude (ROM), and more relaxed movements are congruent with changes towards less protective movements related to improved LBP in two previous systematic reviews (Wernli, Tan, et al., 2020; Wernli et al., 2021 (in press)). While previous work has demonstrated changes in pain cognitions and emotions as important mediators for reduced LBP disability (H. Lee et al., 2017), the role of posture and movement in this relationship has been less clear.

6.5.3.3 Nonconscious non-protection

Seven participants reported progressing to automatic, habitual, fearless, and more normal non-protective patterns that were also associated with faster, greater amplitude (ROM), and more relaxed spinal movements and postures – kinematic and EMG features that resemble people without LBP (Geisser et al., 2005; Laird et al., 2014; Laird et al., 2019). The participants' report of a return to 'normal' movements and postures at follow-up suggests a continuum; from carefree and non-protective before the onset of LBP, to careful and protective while experiencing LBP, back to carefree and non-protective following recovery. These findings share similarities to the concept behind the 'forgotten joint scale', which asserts that a normal healthy joint demands no awareness (Behrend et al., 2012). That changes in pain self-efficacy and pain catastrophising distinguished between the conscious and nonconscious non-protection groups highlights their potential importance in the progression to nonconscious non-protection. Further, it provides a form of validation for the qualitatively derived groups and supports the potential importance of pain self-efficacy and pain catastrophising in LBP recovery as identified previously (Alhowimel et al., 2018; Asenlöf & Söderlund, 2010; H. Lee et al., 2017; Mansell, Storheim, et al., 2017; Smeets et al., 2006), however, the directional nature of these factors remains unclear.

Together these findings support an interplay between less protective movements and postures, positive mindset shift, reduced fear and emotional distress, and improved LBP. Given the multidimensional nature of the CFT intervention, the directional nature of these factors remains unclear. Caneiro et al. (2019) previously reported that changes in cognitive and emotional factors appear to coincide with changes in LBP-related disability and proposed the concept of a shift in the entire pain schema. This research suggests that movement and posture may form part of this schema for people with LBP.

6.5.4 Study considerations

The design of this study limits abilities to make causal inferences about mechanisms and mediators of outcome. Additionally, the design precluded further purposive sampling of participants similar to P1 who did not change, which may have led to additional insights. Nevertheless, reaching codebook saturation after seven participants, with the following five participants confirming the codebook, strengthens the study's validity (Fusch & Ness, 2015). The findings reflect how these 12 individuals with persistent, disabling non-specific LBP conceptualised the relationship between movement, posture, and LBP, before and after a CFT intervention. As with any qualitative investigation, alternative interpretations may exist. Through prolonged engagement with the participants, frequent reflexivity, searching for negative cases, peer review analysis, thick description, and reaching data saturation, we believe we have described meaningful, representative findings that yield clinically applicable insights (Shenton, 2004). As the study only involved 12 people, clinicians should consider the profile of their clinical population to those of this study when considering generalisability. Further, the distinctions between conscious and nonconscious protection, and conscious and non-conscious non-protection were based on the qualitative findings of these 12 people and these require further investigation and development using other methods. These findings may therefore have limited transferability and should be interpreted cautiously until replicated. The potential for desirability bias should also be considered. Additionally, different designs (such as RCTs with mediation analyses) and larger cohorts utilising individualised measures and interventions would prove helpful in answering causal questions.

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6.7 Conflicts of interest disclosures

POS receives speaker fees for lectures and workshops on the biopsychosocial management of pain.

6.8 Funding

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6.9 Role of Funders/Sponsors

The funders/sponsors had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

6.10 Figure legend

Figure 1. The data collection and analysis procedures of the convergent mixed methods design presented graphically.

[a] Pain intensity, bothersomeness, interference, pain control, and trust in back were captured weekly during the baseline and follow-up phases and averaged.

Figure 2. The journey from pain and protection to non-protection and just living.

6.11 Tables

6.11.1 Participant demographics

Table 6.1 Participant demographics. Mixed methods

Table 1. Additional demographic and clinical details presented in appendix 3

Participant	Key baseline demographics				
	Age (years)	Gender	Duration of LBP	RMDQ (0-23)	Örebro (10-item) (0-100)
P1	76	Female	1 year (episodic 15 years)	15	58
P2	38	Male	5 years and 3 months	17	54
P3	40	Female	1 year 8 months	18	57
P4	33	Male	9 years	16	56
P5	68	Male	5-6 years	12	45
P6	28	Female	11 months	19	79
P7	26	Female	7 years	22	49
P8	50	Female	5 years	18	54
P9	43	Male	17 years	10	60
P10	22	Female	6 years	12	67
P11	26	Male	6 years	19	68
P12	56	Male	3 years	18	41

Abbreviations: LBP, low back pain; RMDQ, 23-Item Roland Morris Disability Questionnaire.

6.11.2 Joint display

Table 6.2 Joint display table. Mixed methods

Table 2. Integrating the qualitative and quantitative findings for three exemplar cases from each qualitative group based on the follow-up interviews. P1-conscious protection, P5-conscious non-protection, and P8-nonconscious non-protection

	Qualitative		Quantitative		
Participant. Group membership at follow-up	Baseline (B)	Follow-up (FU)	Measure	B	FU
Participant 1. Remained in the protection group.	"Getting more and more stiff. Well, it spasms, isn't it? Would you call it spasms?"	"KW: has your stiffness from muscle spasm changed? P1: No, I think it's there constantly. It doesn't really change."	Bending:		
			ROM[a]	110°	115°
			Speed[a]	30°/s	51°/s
			Muscle activity[a]	NA	NA
"I'm probably careful not to go sideways or off the centre too much… By coming up straight. Not sideways or twitching left or right, coming up straight... because I'm scared of what might happen if I don't." - P1, follow-up interview	"Thinking back, there might have been some damage done there."	"to me it's just that I've got, I've done some damage there…. And to just do the normal things I'm at a disadvantage because my back doesn't like it anymore and until it's repaired, It's not going to give me less pain)"	Pain[a]		
			Intensity[b]	6.1	5.1
			Interference	5.8	4.6
			Bothersomeness	7.8	4.8
			Activity limitation:		
			RMDQ[c]	15	14
			Bending PSFS[a]	6.8	7.2
			Psychological factors:		
			TSK[c]	36.5	30
			PSEQ[c]	54.5	51
			PCS[c]	21	17
			FreBAQ[c]	15	11
			BAckPAQ[c]	-1	0
			Pain Control[a]	4	6.3
			Trust in back[a]	2.2	3.2

Participant 5. Progressed to the conscious non-protection group. “I'd like to be able to do it instinctively, but things aren't instinctive yet. I still haven’t learnt the new method as an instinct, I've got to break away from the old methods. It takes time.” - P5, follow-up interview	“(movement is) probably more rigid than anything else. Because my back seems to get stuck, lacks its fluidity. It's not fluid at all. I don't feel it’s a smooth movement in any direction on my back at all. No smoothness.”	“(Movement is) fluid and coordinated. You're not taking your next step worrying about the pain coming. Again, you're probably more relaxed… It’s far more fluid. It’s certainly not spasmodic… there's less tension there than there was before. Some of the tension before I created myself… by bracing, breathing in and tensing the muscles up before I tried anything. I think that made it worse… I'd like to have somebody do a measure of my body tension, because I would think my body tension has gone down by about half, easily.”	Bending: ROM[a] Speed[a] Muscle activity[a] Sitting: Pelvic angle (positive = APT)[a]	 70.2° 45.6°/s 0.001 1.3°	 87° 44.3°/s 0.0006 1.5°
	“KW: In terms of predicting your back pain? P5: No control at all…None. That’s the frustration…I just get angry every now and then… particularly when you’ve gone for a week, no drama at all and all of a sudden, bingo. Where did that come from?”	“KW: How much control do you feel you have over your pain now? P5: A lot. Not a hundred percent, but a lot. KW: How do you control it? P5: By thinking before I leap… KW: When you say you think before you leap, what are you thinking about? P5: Oh, the breathing and relaxing, you know, just not that tension. Try and reduce the tension in your body.”	Pain[a] Intensity[b] Interference Bothersomeness Activity limitation: RMDQ[c] Bending PSFS[a] Sitting PSFS[a] Psychological factors: TSK[c] PSEQ[c] PCS[c] FreBAQ[c] BAckPAQ[c] Pain Control[a] Trust in back[a]	 5.7 5.8 6.2 12 5.8 4.7 34.5 49.5 8.5 11 -3 4.9 5.2	 1.7 1 1 8 1.6 0.4 35 40 10 10 6 8.7 7.8
Participant 8. Progressed to the nonconscious non-protection group.	“(stiffness) It’s what I feel. I’m putting it down to stiffness; whether it is stiffness or whether it’s actually a bit more than that I’m unsure… I’m	“There is a lot more flexibility in the muscles right now (my movement) feels more free…doesn’t feel so restricted.” “If I stand how I would normally with my back pretty what I call straight, it just puts tension	Standing: Pelvic tilt (positive = APT)[a] Bending: ROM[a] Speed[a]	 26.6° 74.8° 29.5°/s	 23.7° 94.6° 59.7°/s

"Before it was a lot more of, there was lots of thought that went into that bend and it's like: 'can I actually do this?'. 'Is it going to hurt?', 'just be careful'. Whereas now it's just automatic. I bend, I pick up, I come up, and that's good." - P8, follow-up interview	unsure if there's been more damage, or is it just stiffness, I don't know."	through the whole back and into the glutes. So, but whereas if I lean forward a tinge... it just takes the pressure off… it releases, it relaxes, there is no tension… there's no pain then."	Muscle activity[a]	0.0002	<.00001
	"I think (the damage is) coming from I would say would be the fall I had (5 years ago), and damage to, I don't know that, I think my guess would be something in the lower back…my thought is something's broken or something's tight. Somethings not working."	"(movement) actually feels really good. So, I'm not afraid to bend. I'm not afraid to pick up things off the floor… What un-packed it for me was moving and realizing that it's not damaging anything. It won't damage anything… to get rid of that damage idea, was a big thing for me."	Pain[a]		
			Intensity[b]	5.8	0
			Interference	3.7	0
			Bothersomeness	5.0	0
			Activity limitation:		
			RMDQ[c]	18	0
			Standing PSFS[a]	6.3	0
			Bending PSFS[a]	5.3	0
			Psychological factors:		
			TSK[c]	37.5	18
			PSEQ[c]	37.5	60
			PCS[c]	15.5	0
			FreBAQ[c]	18	2
			BAckPAQ[c]	4	50
			Pain Control[a]	4.6	10
			Trust in back[a]	2.8	10

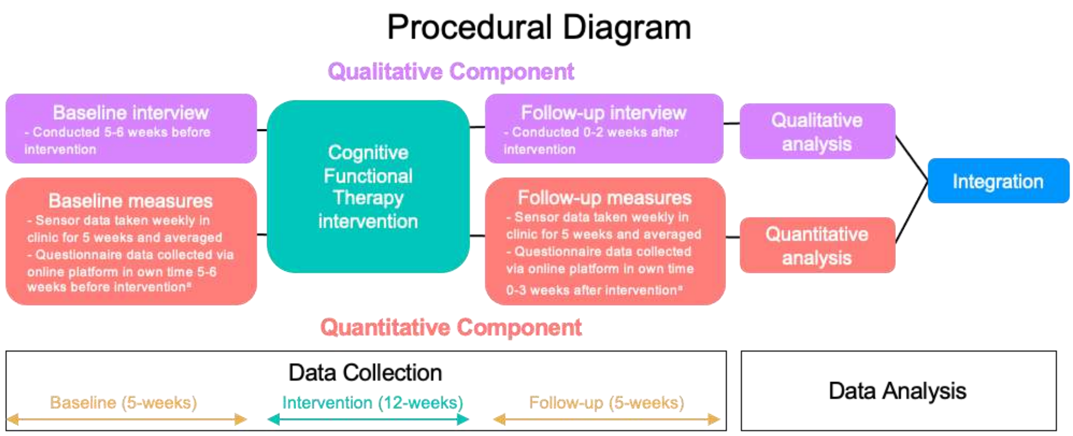
Key: ROM, Range of Motion, RMDQ; Roland Morris Disability Questionnaire, PSFS; Patient-Specific Functional Scale, TSK; Tampa Scale of Kinesiophobia, PSEQ; Pain self-efficacy questionnaire, PCS; Pain catastrophising scale, FreBAQ, Fremantle Back Awareness Questionnaire, BackPAQ; Back Pain Attitudes Questionnaire, APT; Anterior Pelvic Tilt

[a] Mean of weekly measure during baseline and follow-up period
[b] Mean of current pain, worst pain over last week, and average pain over last week.
[c] Mean of baseline 1 and baseline 2 long questionnaire

6.12 Figures

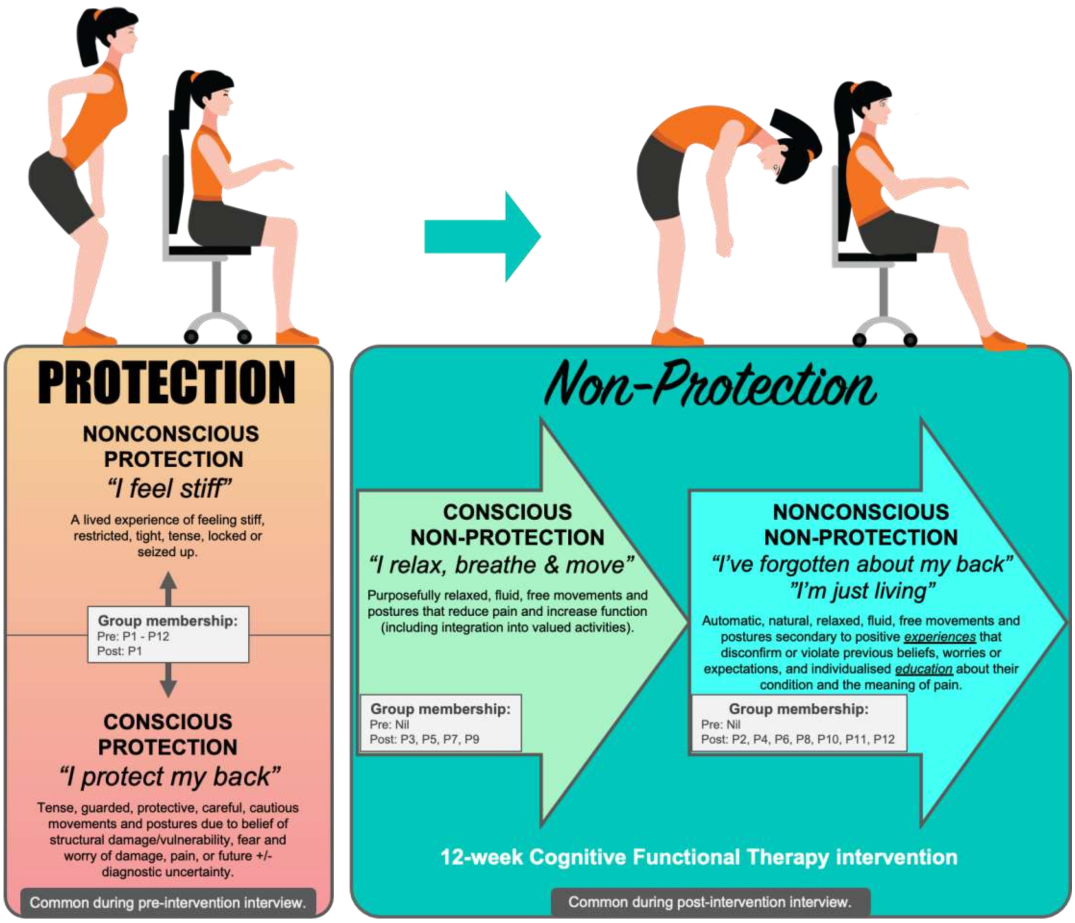
6.12.1 Figure 1

Figure 6-1 Procedural diagram. Mixed methods



6.12.2 Figure 2

Figure 6-2 Model representing protection to non-protection. Mixed methods



6.13 Chapter 6 Appendices

6.13.1 Appendix 1. Sample interview schedule

1. Tell me the story about your back pain…

2. What have you been told about your back pain?

    a. Have you been told anything about the way you move or your posture?

3. Can you describe to me any activities or tasks that you do most days that you find difficult to perform or that make your pain worse? (Refer to Patient-Specific Functional Scale to confirm)

    a. How do you think (*insert answer from Q3)* makes your pain worse?

    b. Can you imagine yourself (*insert answer from Q3*), put me in your shoes and tell me what you feel when you do this?

    c. What do you think this is telling you? Why do you think this?

    d. Can you describe to me the thoughts that would be running through your head? Why do you think this?

    e. Can you describe any emotions you experience when you (*insert answer)*?

    f. Does (*insert answer)* worry you?

    g. If I were to film you doing (insert answer) now and compare that to film of you (insert answer) before your pain, would it be different? How? Why?

    h. How does moving like this influence your pain?

4. Are there any other movements or postures that make your pain worse?

    a. REPEAT 3A-F

5. Can you describe to me any movements or postures that make your pain better?
    a. Why do you think this is?

6. What happens to your movement or posture when you are in pain?
    a. Why do you think this happens?

7. Do you deliberately change the way you move or position yourself because of pain?
    a. Can you give me an example of this?
    b. Why do you do this?
    c. In what way does this influence your pain?

8. Do you have a picture of your back (in your head)? Can you share this with me?

9. Do you protect your back? How? (Do you feel relaxed in your back?)

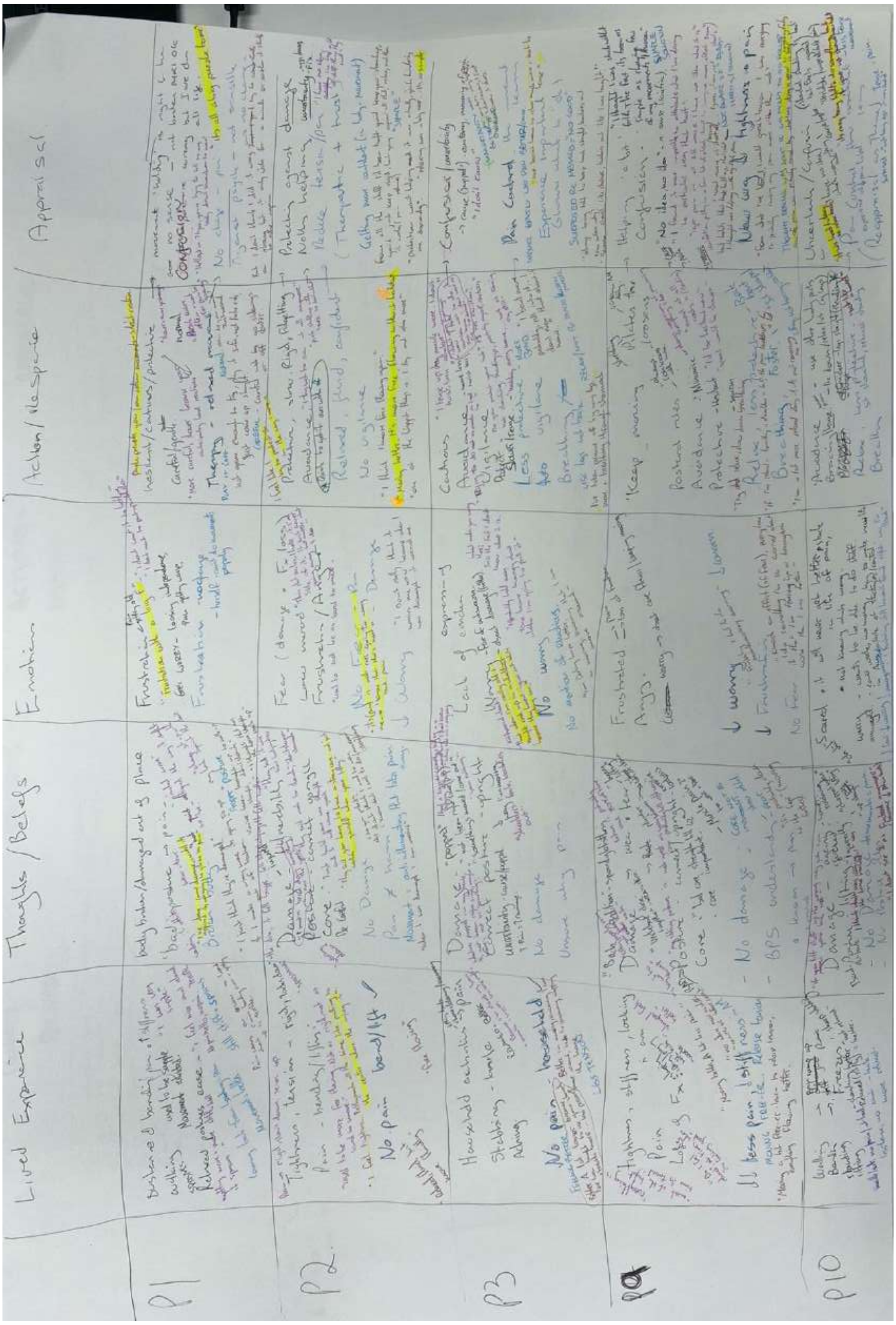
10. How much control do you have over your pain?

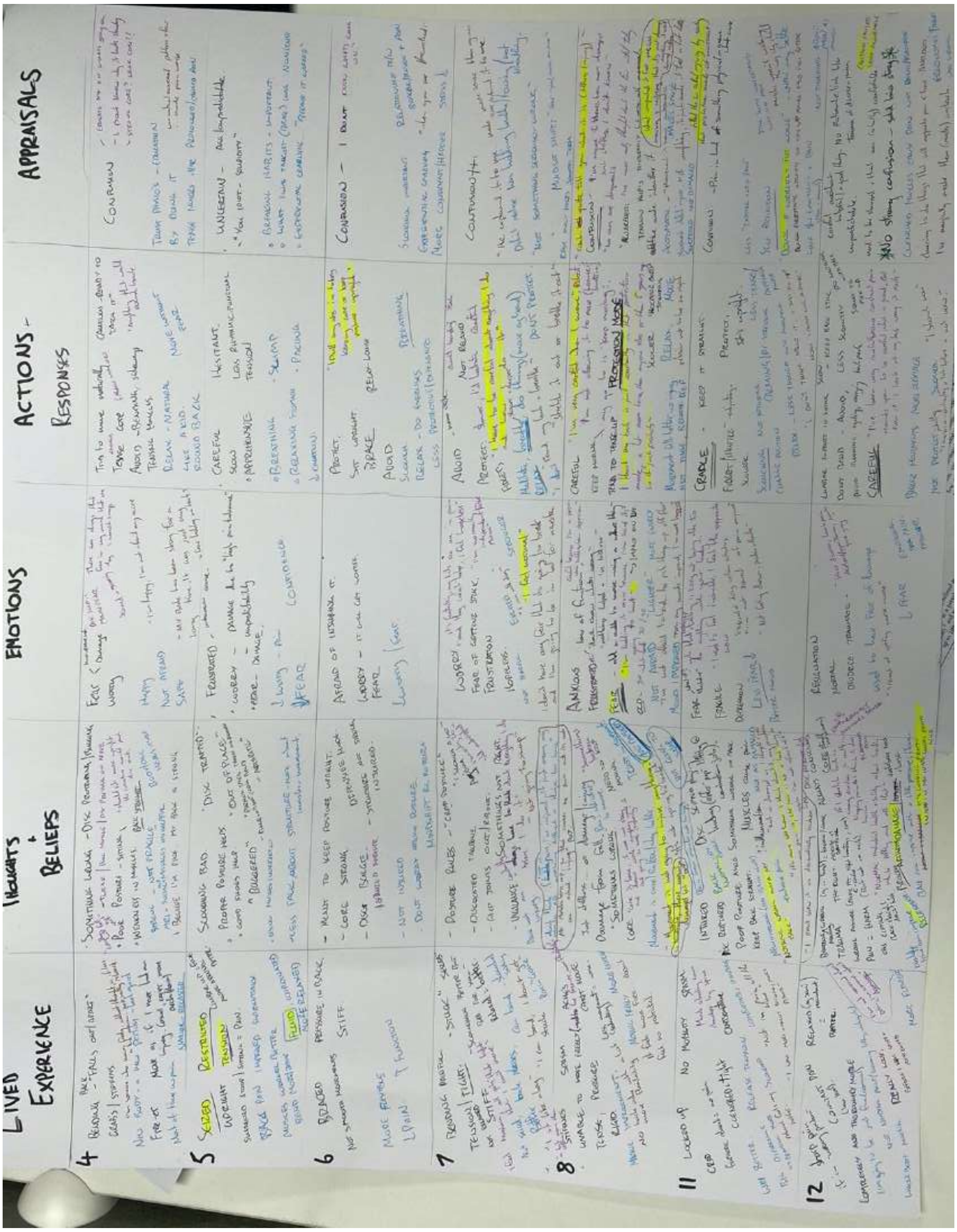
11. Can you tell me about any previous treatment for your back pain and what it involved? (INITIAL INTERVIEW ONLY)
    a. How did this influence your back pain?

12. What do you think it will take to improve your back pain? (INITIAL INTERVIEW ONLY)

6.13.2 Appendix 2. Charting data for each participant to help identify salient intra-person codes

Figure 6-3 Appendix 2. Charting qualitative data. Mixed Methods




LIVED EXPERIENCE
THOUGHTS + BELIEFS
EMOTIONS
ACTIONS - RESPONSES
APPRAISALS

6.13.3 Appendix 3. Detailed descriptions and quantitative data for all participants

6.13.3.1 Detailed descriptions of each participant

Table 6.3 Appendix 3. Detailed demographics. Mixed methods

Participant	Key demographic and clinical features	Patient-Specific Functional Limitations
P1	**Age and Gender:** 76-year-old female **Duration of LBP:** Intermittent for ~15 years, intensified over last year Education level: School Occupation: Retired **Ethnicity:** Dutch **Previous interventions:** Physiotherapy, massage, general practitioner and radiology **Co-morbidities:** 2 cardiac stents, reflux, bronchiectasis **Family history of LBP:** 2 brothers (long-term history, numerous interventions, not recovered). **LBP onset:** Insidious (current episode potentially linked to sit-ups) Recruitment source: Social media	Bending Walking Vacuuming
P2	**Age and Gender:** 38-year-old male **Duration of LBP:** 5 years and 3 months **Education level:** School **Occupation:** Real-estate/father **Ethnicity:** Australian **Previous interventions:** Extensive physiotherapy, general practitioner, analgesics, stopping physical activities. Co-morbidities: Migraines **Family history of LBP:** Father (20-year history, not recovered, manages) **LBP onset:** Insidious**,** potentially following sustained squat position Recruitment source: Word of mouth	Bending **Lifting** (for example, the kids) **Sitting** (sitting on the floor and getting up)
P3	**Age and Gender:** 40-year-old female **Duration of LBP:** 1 year 8 months **Education level:** School **Occupation:** Mother/cleaner (unable to work at the start of study due to LBP) **Ethnicity:** Australian **Previous interventions:** Physiotherapy, massage, chiropractic and general practitioner. Co-morbidities: Nil Family history of LBP: nil **LBP onset:** Felt pop in back during birth of youngest child (complicated delivery) Recruitment source: Social media	Bending Lifting Vacuuming
P4	**Age and Gender:** 33-year-old male Duration of LBP: 9 years **Education level:** University **Occupation:** Health Recruiter (~20 days off work due to LBP) **Ethnicity:** Australian **Previous interventions:** Extensive chiropractic, physiotherapy, massage, general practitioner, radiology medication (Ibrufen and paracetamol as required). Co-morbidities: Nil	Sitting Bending Standing

	Family history of LBP: Mother (10-year history, not recovered) and sister (1-year history, not recovered). **LBP onset:** Strain playing basketball 9 years ago – got knocked over Recruitment source: Social media	
P5	**Age and Gender:** 68-year-old male Duration of LBP: 5-6 years **Education level:** School **Occupation:** Retired school teacher **Ethnicity:** Australian **Previous interventions:** Physiotherapy, exercise, massage, general practitioner, radiology, facet-joint injections, epidural and medication (occasional anti-inflammatory) Co-morbidities: Mild anxiety **Family history of LBP:** Father (long-term history, back fusion, not recovered) and brother (long-term history, managing, not recovered) **LBP onset: I**nitially felt at golf. Current episode insidious Recruitment source: Social media	Bending **Sitting (**for example while driving) Putting on socks
P6	**Age and Gender:** 28-year-old female Duration of LBP: 11 months **Education level:** University **Occupation:** Disability leave, ~6 months off work due to LBP, mother **Ethnicity:** Chinese **Previous interventions:** Physiotherapy, remedial massage, chiropractic, osteopathy, general practitioner, radiology. **Co-morbidities:** High cholesterol **Family history of LBP:** Mother (long term, managing, not recovered) **LBP onset:** Around time of birth of first child. **Recruitment source:** Referral from primary care practitioner	Lifting Sitting Doing dishes
P7	**Age and Gender:** 26-year-old female Duration of LBP: 7 years Education level: School Occupation: Mother **Ethnicity:** Australian **Previous treatments:** Physiotherapy, massage, general practitioner and medication (Pristiq, Tramadol, Codapane Forte) Co-morbidities: Depression Family history of LBP: Nil **LBP onset:** Around time of birth of first child. Recruitment source: Social media	Bending Sitting Walking
P8	**Age and Gender:** 50-year-old female Duration of LBP: 5 years **Education level:** University **Occupation:** Counsellor (10 days off work due to LBP) **Ethnicity:** Australian **Previous interventions:** Physiotherapy, massage, general practitioner and medication (Plaquenil, Pristiq, Thyroxine, occasional analgesics and anti-inflammatories) **Co-morbidities:** Lupus, hypothyroidism, depression and anxiety **Family history of LBP:** Sister (long-term, not recovered) and father (long-term, not recovered) **LBP onset:** fall from chair onto tiled floor 5 years ago. Recruitment source: Social media	Standing Bending Walking
P9	**Age and Gender:** 43-year-old male Duration of LBP: 17 years **Education level:** School **Occupation:** Own's sign fabrication and installation business (unable to take days off due to nature of occupation)	**Sitting** (for long periods) **Lifting** (for example, the kids, signs)

	Ethnicity: Australian **Previous interventions:** Regular massage and Pilates. Chiropractic, exercise physiologist, osteopath, physiotherapy, craniosacral therapy, general practitioner and medication (anti-inflammatories almost daily, now ~once per week). Co-morbidities: Nil Family history of LBP: Nil LBP onset: Insidious Recruitment source: Social media	**Bending** (predominantly in the morning) Sustained **extension** (for example rope access work).
P10	**Age and Gender:** 22-year-old female Duration of LBP: 6 years Education level: School Occupation: unemployed **Ethnicity:** Irish **Previous interventions:** Physiotherapy, general practitioner, radiology, medication (Lyrica, Codeine, Paracetamol) **Co-morbidities:** Depression, anxiety, post-traumatic stress disorder. **Family history of LBP:** Nil **LBP onset:** Insidious around time of stressful life event **Recruitment source:** Referral from primary care practitioner	Bending Standing Walking
P11	**Age and Gender:** 26-year-old male Duration of LBP: 6 years **Education level:** School **Occupation:** Unemployed due to LBP (for ~4 years) **Ethnicity:** Australian **Previous interventions:** Spinal surgery (2x Microdiscectomy, 1x spinal Fusion), 2x Corticosteroid injections), physiotherapy, massage, general practitioner and medication (Pristiq, Lyrica, Tramal, Norspan, Palexia) Co-morbidities: Nil Family history of LBP: Nil **LBP onset:** playing national-level hockey. Recruitment source: Word of mouth	Sitting Bending Standing
P12	**Age and Gender:** 56-year-old male Duration of LBP: 3 years **Education level:** University **Occupation:** Engineer (~30 days off work due to LBP) **Ethnicity:** Australian **Previous interventions:** Physiotherapy, general practitioner, gentle exercise, consulted multiple spinal surgeons and tertiary care practitioners. **Co-morbidities:** Depression, minor bursitis and tinnitus **Family history of LBP:** Sister (long-term, not recovered) and brother (long-term, not recovered) **LBP onset:** Lifting in the gym. Recruitment source: Social media	Lifting Vacuuming Walking Bending

6.13.3.2 In table form

Table 6.4 Appendix 3. Detailed quantitative findings for each participant. Mixed methods

Participant	Outcome measure	Baseline	Follow-up
P1 Participant 1, 73yo female Remained in conscious protection group based on follow-up interview	**Pain**[a] (0-10, higher = worse)		
	Intensity (Tri.NRS)	6.1	5.1
	Interference	5.8	4.6
	Bothersomeness	7.8	4.8
	Activity Limitation		
	RMDQ[b] (0-23, higher = worse)	15	13
	PSFS[a] (0-10, higher = worse)		
	Bending	6.8	7.2
	Fear of movement		
	TSK[b] (17-68, higher = worse)	36.5	30
	Pain self-efficacy		
	PSEQ[b] (0-60, higher = better)	54.5	51
	Pain catastrophising		
	PCS[b] (0-52, higher = worse)	21	17
	Back perceptions		
	FreBAQ[b] (0-36, higher = worse)	15	11
	Back beliefs		
	BackPAQ[b] (-68 to +68, higher = better)	-1	0
	Pain Control[a] (0-10, higher = better)	4	6.3
	Trust in back[a] (0-10, higher = better)	2.2	3.2
	Movement/Posture[a]		
	Bending ROM	110°	114.8°
	Bending Speed	30°/s	51°/s
	Muscle activity (%Submax)	N/A	N/A
P2 Participant 2, 38yo male Progressed to nonconscious non-protection group based on follow-up interview	**Pain**[a] (0-10, higher = worse)		
	Intensity (Tri.NRS)	4	0.5
	Interference	6.8	0
	Bothersomeness	5	0.6
	Activity Limitation		
	RMDQ[b] (0-23, higher = worse)	17	0
	PSFS[a] (0-10, higher = worse)		
	Bending	6.6	1.4
	Fear of movement		
	TSK[b] (17-68, higher = worse)	47	20
	Pain self-efficacy		
	PSEQ[b] (0-60, higher = better)	31.5	60
	Pain catastrophising		
	PCS[b] (0-52, higher = worse)	35	1
	Back perceptions		
	FreBAQ[b] (0-36, higher = worse)	21.5	3
	Back beliefs		
	BackPAQ[b] (-68 to +68, higher = better)	-27.5	52
	Pain Control[a] (0-10, higher = better)	4.3	9.9
	Trust in back[a] (0-10, higher = better)	3.2	10
	Movement/Posture[a]		
	Bending ROM	85.7°	106°
	Bending Speed	43.3°/s	65.4°/s
	Muscle activity (%Submax)	0.006	<.001
P3	**Pain**[a] (0-10, higher = worse)		
	Intensity (Tri.NRS)	7.4	2.1
	Interference	6	0.8

	Outcome measure	Baseline	Follow-up
Participant 3, 40yo female Progressed to conscious non-protection group based on follow-up interview	Bothersomeness	7.2	1.2
	Activity Limitation		
	RMDQ[b] (0-23, higher = worse)	18	5
	PSFS[a] (0-10, higher = worse)		
	Bending	6.8	1.0
	Fear of movement		
	TSK[b] (17-68, higher = worse)	43.5	37
	Pain self-efficacy		
	PSEQ[b] (0-60, higher = better)	35.5	57
	Pain catastrophising		
	PCS[b] (0-52, higher = worse)	30.5	6
	Back perceptions		
	FreBAQ[b] (0-36, higher = worse)	16	1
	Back beliefs		
	BackPAQ[b] (-68 to +68, higher = better)	-18.5	5
	Pain Control[a] (0-10, higher = better)	6.7	9.8
	Trust in back[a] (0-10, higher = better)	5.3	9
	Movement/Posture[a]		
	Bending ROM	60.9°	90.9°
	Bending Speed	41.2°/s	59.2°/s
	Muscle activity (%Submax)	<0.001	<0.001
P4 Participant 4, 33yo male Progressed to nonconscious non-protection group based on follow-up interview	**Pain[a]** (0-10, higher = worse)		
	Intensity (Tri.NRS)	4.1	0.1
	Interference	4.3	0.0
	Bothersomeness	4.8	0.2
	Activity Limitation		
	RMDQ[b] (0-23, higher = worse)	16	0
	PSFS[a] (0-10, higher = worse)		
	Bending	4.5	0.2
	Sitting	3.8	0
	Fear of movement		
	TSK[b] (17-68, higher = worse)	44	21
	Pain self-efficacy		
	PSEQ[b] (0-60, higher = better)	48.5	60
	Pain catastrophising		
	PCS[b] (0-52, higher = worse)	28	1
	Back perceptions		
	FreBAQ[b] (0-36, higher = worse)	18	3
	Back beliefs		
	BackPAQ[b] (-68 to +68, higher = better)	-28.5	35
	Pain Control[a] (0-10, higher = better)	3.3	8.5
	Trust in back[a] (0-10, higher = better)	2.8	10
	Movement/Posture[a]		
	Bending ROM	99.8°	107.9°
	Bending Speed	26.7°/s	62.1°/s
	Muscle activity (%Submax)	0.05	<0.001
	Sitting pelvic tilt (↑ = APT)	-4.8□	-7.6□
P5 Participant 5, 68yo male Progressed to conscious	**Pain[a]** (0-10, higher = worse)		
	Intensity (Tri.NRS)	5.7	1.7
	Interference	5.8	1.0
	Bothersomeness	6.2	1.0
	Activity Limitation		
	RMDQ[b] (0-23, higher = worse)	12	8
	PSFS[a] (0-10, higher = worse)		
	Bending	5.8	1.6
	Sitting	4.7	0.4

	Outcome measure	Baseline	Follow-up
	Fear of movement		
	TSK[b] (17-68, higher = worse)	34.5	35
	Pain self-efficacy		
	PSEQ[b] (0-60, higher = better)	49.5	40
	Pain catastrophising		
	PCS[b] (0-52, higher = worse)	8.5	10
	Back perceptions		
	FreBAQ[b] (0-36, higher = worse)	11	10
	Back beliefs		
	BackPAQ[b] (-68 to +68, higher = better)	-3	6
	Pain Control[a] (0-10, higher = better)	4.9	8.7
	Trust in back[a] (0-10, higher = better)	5.2	7.8
	Movement/Posture[a]		
	Bending ROM	70.2°	87°
	Bending Speed	45.6°/s	44.3°/s
	Muscle activity (%Submax)	0.001	0.0006
	Sitting pelvic tilt (↑ = APT)	1.3□	1.5□
P6 Participant 6, 28yo female Progressed to nonconscious non-protection group based on follow-up interview	**Pain[a]** (0-10, higher = worse)		
	Intensity (Tri.NRS)	8.1	2.0
	Interference	8.7	1.4
	Bothersomeness	9	1.8
	Activity Limitation		
	RMDQ[b] (0-23, higher = worse)	19	0
	PSFS[a] (0-10, higher = worse)		
	Lifting	7.8	1.4
	Sitting	8.2	2.6
	Fear of movement		
	TSK[b] (17-68, higher = worse)	50.5	32
	Pain self-efficacy		
	PSEQ[b] (0-60, higher = better)	26	52
	Pain catastrophising		
	PCS[b] (0-52, higher = worse)	34.5	4
	Back perceptions		
	FreBAQ[b] (0-36, higher = worse)	21	9
	Back beliefs		
	BackPAQ[b] (-68 to +68, higher = better)	-20	14
	Pain Control[a] (0-10, higher = better)	2	7.6
	Trust in back[a] (0-10, higher = better)	1.5	7.5
	Movement/Posture[a]		
	Lifting ROM	65°	82.3°
	Lifting Speed	48.2°/s	67.3°/s
	Sitting pelvic tilt (↑ = APT)	3.1°	-4.5°
P7 Participant 7, 26yo female Progressed to conscious non-protection group based on follow-up interview w	**Pain[a]** (0-10, higher = worse)		
	Intensity (Tri.NRS)	6.1	5.1
	Interference	5.8	4.6
	Bothersomeness	7.8	4.8
	Activity Limitation		
	RMDQ[b] (0-23, higher = worse)	22	0
	PSFS[a] (0-10, higher = worse)		
	Bending	4.3	1
	Sitting	3.5	0
	Fear of movement		
	TSK[b] (17-68, higher = worse)	45.5	34
	Pain self-efficacy		
	PSEQ[b] (0-60, higher = better)	31	47
	Pain catastrophising		
	PCS[b] (0-52, higher = worse)	7.5	0

Participant	Outcome measure	Baseline	Follow-up
	Back perceptions		
	FreBAQ[b] (0-36, higher = worse)	11.5	8
	Back beliefs		
	BackPAQ[b] (-68 to +68, higher = better)	-22.5	16
	Pain Control[a] (0-10, higher = better)	2.6	8.3
	Trust in back[a] (0-10, higher = better)	2.8	7.8
	Movement/Posture[a]		
	Bending ROM	108°	103.7°
	Bending Speed	70°/s	76.6°/s
	Muscle activity (%Submax)	<0.001	<0.001
	Sitting pelvic tilt (↑ = APT)	2.0°	7.7°
P8 Participant 8, 50yo female Progressed to nonconscious non-protection group based on follow-up interview	**Pain[a]** (0-10, higher = worse)		
	Intensity (Tri.NRS)	5.8	0
	Interference	3.7	0
	Bothersomeness	5.0	0
	Activity Limitation		
	RMDQ[b] (0-23, higher = worse)	18	0
	PSFS[a] (0-10, higher = worse)		
	Bending	5.3	0
	Standing	6.3	0
	Fear of movement		
	TSK[b] (17-68, higher = worse)	37.5	18
	Pain self-efficacy		
	PSEQ[b] (0-60, higher = better)	37.5	60
	Pain catastrophising		
	PCS[b] (0-52, higher = worse)	15.5	0
	Back perceptions		
	FreBAQ[b] (0-36, higher = worse)	18	2
	Back beliefs		
	BackPAQ[b] (-68 to +68, higher = better)	4	50
	Pain Control[a] (0-10, higher = better)	4.6	10
	Trust in back[a] (0-10, higher = better)	2.8	10
	Movement/Posture[a]		
	Bending ROM	74.8°	94.6°
	Bending Speed	29.5°/s	59.7°/s
	Muscle activity (%Submax)	0.0002	<0.00001
	Standing pelvic tilt (↑ = APT)	26.6°	23.7°
P9 Participant 9, 43yo male Progressed to conscious non-protection group based on follow-up interview	**Pain[a]** (0-10, higher = worse)		
	Intensity (Tri.NRS)	3.7	1.1
	Interference	4.2	0.4
	Bothersomeness	4.7	1
	Activity Limitation		
	RMDQ[b] (0-23, higher = worse)	10	0
	PSFS[a] (0-10, higher = worse)		
	Bending	5.5	0.8
	Extension (sustained)	6.6	1.0
	Fear of movement		
	TSK[b] (17-68, higher = worse)	41	17
	Pain self-efficacy		
	PSEQ[b] (0-60, higher = better)	48.5	59
	Pain catastrophising		
	PCS[b] (0-52, higher = worse)	8.5	2
	Back perceptions		
	FreBAQ[b] (0-36, higher = worse)	7	0
	Back beliefs		
	BackPAQ[b] (-68 to +68, higher = better)	-24.5	32
	Pain Control[a] (0-10, higher = better)	3.2	8

	Outcome measure	Baseline	Follow-up
	Trust in back[a] (0-10, higher = better)	2.8	8.2
	Movement/Posture[a]		
	Bending ROM	97.7°	99.2°
	Bending Speed	28°/s	54.1°/s
	Muscle activity (%Submax)	0.007	<0.001
	Extension ROM (↑ = flexion)	-26.7°	-26.9°
P10 Participant 10, 22yo female Progressed to nonconscious non-protection group based on follow-up interview	**Pain**[a] (0-10, higher = worse)		
	Intensity (Tri.NRS)	6.5	3.7
	Interference	9.2	1.2
	Bothersomeness	9.0	1.4
	Activity Limitation		
	RMDQ[b] (0-23, higher = worse)	12	3
	PSFS[a] (0-10, higher = worse)		
	Bending	6.7	0.2
	Standing	9.3	2.0
	Fear of movement		
	TSK[b] (17-68, higher = worse)	44.5	27
	Pain self-efficacy		
	PSEQ[b] (0-60, higher = better)	17	49
	Pain catastrophising		
	PCS[b] (0-52, higher = worse)	30.5	5
	Back perceptions		
	FreBAQ[b] (0-36, higher = worse)	2.5	0
	Back beliefs		
	BackPAQ[b] (-68 to +68, higher = better)	-4	29
	Pain Control[a] (0-10, higher = better)	1.6	8.7
	Trust in back[a] (0-10, higher = better)	0	8.8
	Movement/Posture[a]		
	Bending ROM	76.9°	74.7°
	Bending Speed	61.3°/s	72.7°/s
	Muscle activity (%Submax)	N/A	N/A
	Standing pelvic tilt (↑ = APT)	11.6°	10.3
P11 Participant 11, 26yo male Progressed to nonconscious non-protection group based on follow-up interview	**Pain**[a] (0-10, higher = worse)		
	Intensity (Tri.NRS)	7.7	2.0
	Interference	6.8	1.2
	Bothersomeness	7.6	1.4
	Activity Limitation		
	RMDQ[b] (0-23, higher = worse)	19	6
	PSFS[a] (0-10, higher = worse)		
	Bending	8.6	1.4
	Standing	8.2	1.2
	Fear of movement		
	TSK[b] (17-68, higher = worse)	37	22
	Pain self-efficacy		
	PSEQ[b] (0-60, higher = better)	30.5	49
	Pain catastrophising		
	PCS[b] (0-52, higher = worse)	27	6
	Back perceptions		
	FreBAQ[b] (0-36, higher = worse)	22	10
	Back beliefs		
	BackPAQ[b] (-68 to +68, higher = better)	3	33
	Pain Control[a] (0-10, higher = better)	3.1	6.7
	Trust in back[a] (0-10, higher = better)	2.5	9
	Movement/Posture[a]		
	Bending ROM	57°	87.6°
	Bending Speed	22.6°/s	64.6°/s
	Muscle activity (%Submax)	N/A	N/A

	Outcome measure	Baseline	Follow-up
	Standing pelvic tilt (↑ = APT)	32.6°	22.7°
P12 Participant 12, 56yo male Progressed to nonconscious non-protection group based on follow-up interview	**Pain**[a] (0-10, higher = worse)		
	Intensity (Tri.NRS)	1.3	0.3
	Interference	5.6	0
	Bothersomeness	0.8	0
	Activity Limitation		
	RMDQ[b] (0-23, higher = worse)	18	0
	PSFS[a] (0-10, higher = worse)		
	Bending	7.3	0
	Fear of movement		
	TSK[b] (17-68, higher = worse)	60.5	20
	Pain self-efficacy		
	PSEQ[b] (0-60, higher = better)	34	60
	Pain catastrophising		
	PCS[b] (0-52, higher = worse)	12	0
	Back perceptions		
	FreBAQ[b] (0-36, higher = worse)	10	6
	Back beliefs		
	BackPAQ[b] (-68 to +68, higher = better)	-31.5	28
	Pain Control[a] (0-10, higher = better)	3.3	8.8
	Trust in back[a] (0-10, higher = better)	1	10
	Movement/Posture[a]		
	Bending ROM	79.4°	84.4°
	Bending Speed	29.4°/s	41.2°/s
	Muscle activity (%Submax)	0.0002	<0.0001

Key:
[a] Mean of weekly measure during baseline and follow-up period
[b] Full questionnaires. Baseline, Mean of Baseline 1 and Baseline 2, Follow-up, Follow-up full questionnaire.

Abbreviations:
Tri.NRS, mean of current, average and worst pain over last week on 0-10 numerical rating scale; RMDQ, Roland Morris Disability Questionnaire (23-item); PSFS, Patient-Specific Functional Scale; TSK, Tampa Scale of Kinesiophobia; PSEQ, Pain Self-Efficacy Questionnaire; PCS, Pain Catastrophising Scale; FreBAQ, Fremantle Back Awareness Questionnaire.

6.13.3.3 In graphical form

Figure 6-4 Appendix 3. Radar graph of all participants. Mixed methods

Median values for various domains from all participants with values transformed to a 0-10 scale (higher = worse). ROM; Range of motion, RMDQ; Roland Morris Disability Questionnaire, PSFS; Patient-Specific Functional Scale, LBP; Low back pain.

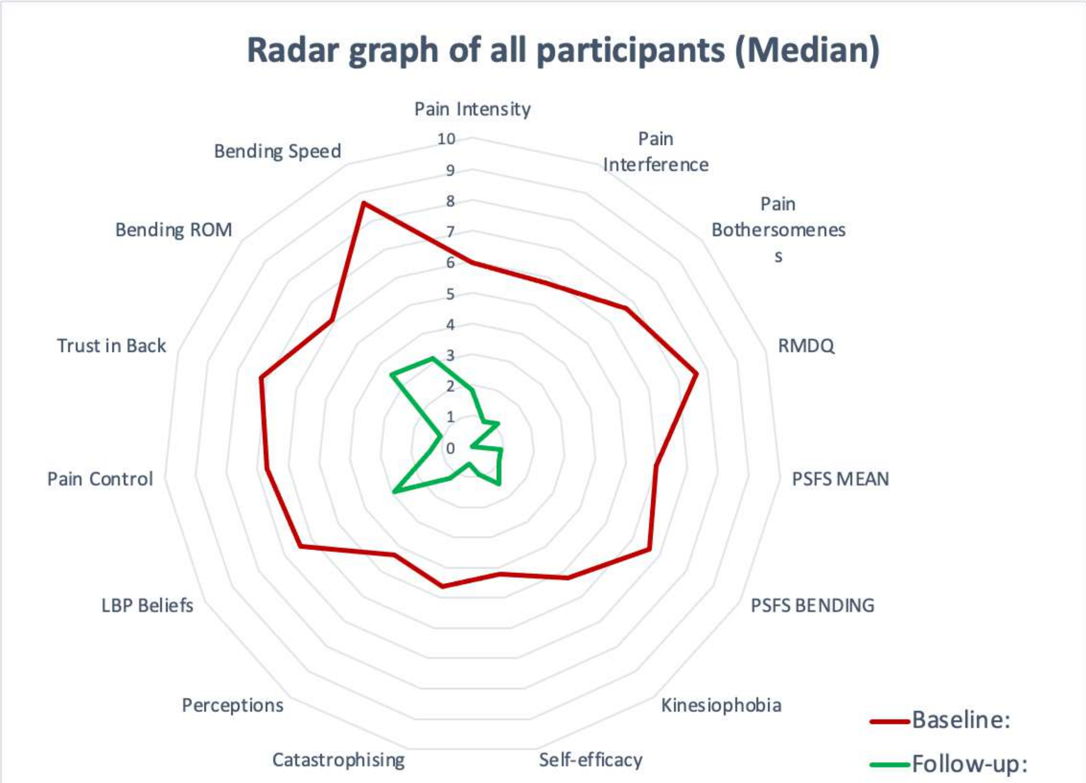


Figure 6-5 **Appendix 3. Radar graphs for individual participants. Mixed methods**

Various domains for each participant with values transformed to a 0-10 scale (higher = worse). B = baseline, FU = follow-up.

6.13.4 Appendix 4. Additional supportive qualitative quotes

Table 6.5 Appendix 4. Additional supportive quotes. Mixed methods

Participant and quote		Interview B = baseline FU = Follow-up
Theme 1: Nonconscious protection (strong pre-intervention theme)		
P1	(The threatening memories) are a bit of a psychological breaker… I think the psyche can prevent you from certain movements because it's in control, when you don't expect it to be—silent, silent creature lying there in wait for its opportunity.	B
P1	KW: What's your normal? P01: Without thinking, I probably tense up again. But I can't spend my whole life relaxed. KW: So why do you think you tense up? P01: Well, I thought that was the norm. Straight and back up. And it probably is the norm because when I look at other people, they don't walk around like this, but they haven't got the back pain.	FU
P2	Your body is saying that's injured. Let's lock it down for a bit… the muscles were locked down and they had been for so long to try and protect that area.	B
P3	(I'm worried) that when I'm really old I might end up in a wheelchair. I don't know, because they haven't figured out what's going on.	B
P3	KW: Do you feel like you're able to let go on land (out of the water)? P3: No, definitely not… KW: Do you find it difficult to relax on the land? P3: Yes. Probably.	B
P4	I just really couldn't move my back. Um, so yeah, that really worried me.	B
P5	No idea. Wish I knew why or how (changing position eases the pain).	B
P5	Probably more rigid than anything else. Because my back seems to get stuck, lacks its fluidity. It's not fluid at all. I don't feel is a smooth movement in any direction on my back at all. No smoothness.	B
P6	It feels like the disc will never be back to where it was. It feels like I'll never be well again. It feels like I might actually need a surgery.	B
P6	It's not allowing movements, like smooth movements.	B
P7	KW: Tell me what you feel in your back when, when you're bending. P7: Tension, kind of thing. I don't know. It feels like it all just gets that tight that I can't move.	B
P7	I've always had like a tense neck and that, but I didn't know my lower back was, I was just like, there's something seriously wrong. But there wasn't.	FU
P8	(Before) it would've been a lot more free-er and had a lot more flexibility.	B
P8	KW: Do you feel relaxed in your back?	B

	Participant and quote	Interview B = baseline FU = Follow-up
	P8: No. No. It's always in protection mode… protecting whatever is wrong.	
P9	I've probably let it go so long the spondylolisthesis or whatever you call it has too much damage, all the tissue is sort of worn out between my vertebrae and everything… it's quite stiff.	B
P10	P:10: I get very stiff and I kind of I walk weird. KW: Describe that to me. P10: Very straight up and…I don't know, kind of like a robot I guess.	B
P10	P10: I don't know. I think it's just from the level of pain that I feel and then yeah, from that level of pain then my body is like, "Oh shit," and then it's like, "I've got to stiffen up," and then I feel the two together and it's like "oh shit" ... KW: And then when you say you've got to stiffen up, is that like a conscious or unconscious response? P10: Yeah. Well, I don't choose it, it just kind of happens.	B
P11	It just feels locked up tight and just feels like something's…it feels like it's locked up so much that it's pulling the muscle and that's what's causing that stabbing pain is because the muscle's being pulled.	B
P11	What goes on when I do get that lock up is the disc comes out, ruptures, and then it puts pressure on my nerve and then that sends a signal up to my brain where it's like "well, something's happened and I've got to protect it." It's just some automatic response from my back brain just protecting it. Yeah. Trying to protect it I suppose. And it's a strange fear. It's just like all your sections of your spine just locked up, just you can't move them. Your body won't let you move them kind of thing. So, it's just a strange feeling. I hate it.	B
P11	I remember sitting there and my back just locked up after that ping. It just fully locked up and I couldn't…had to turn around…my whole body had to turn around if I wanted to turn around and there was just not that mobility in my lower back. That lasted for about two weeks.	B
P12	There is suddenly a bit of stiffness that I notice.	B
Theme 2: Conscious protection (strong pre-intervention theme)		
P2	(My movement used to be) free flowing. Not as rigid, not as scared to move.	B
P2	I didn't do any of the weights where I had to bend my back fully over or anything cause I felt like I would just snap, topple over.	B
P3	By not slouching as much, standing up and sort of protecting myself more of what I do. Cautious.	B
P4	It would tense up. I guess my natural response to any sort of danger would be too tense up and I've sort of trained myself to tense up. Anytime I went into a movement that I thought was unstable, I would tense up as hard as I could, as if I was lifting my, you know, the heaviest weight I could lift. Um, even if it was a pencil I would be yeah, uh, I'd tense as if I was lifting a hundred kilos.	FU
P4	When the pain happens. Um, the thing I can do to control it is to lie down or take, um, take, yeah, pain, pain medicine.	B
P6	It's a bit discouraging considering I am nearing 30, but all the things that I used to be able to do before 28 just seem pretty impossible to do now…I kind of feel like I'll probably be a burden to the society because everyone has to lug me around, or do	B

Participant and quote		Interview B = baseline FU = Follow-up
	things to prop me up, which you don't really want to. I'm not 70 yet. No one has to do that for me.	
P7	I feel like my spine is going to fall through to my stomach.	B
P7	I have to be careful about everything I do and how I do everything.	B
P7	But probably I wouldn't be like relaxed sitting… I used to be able to relax, sitting down, like slouch in the chair or, you know, sit comfortably in a chair. I can't do that. I have to constantly move… otherwise my back seizes, or my butt seizes, one of the two.	B
P7	KW: How much control do you feel you have over your pain? None, unless I take medication, but I don’t like taking medication… so when my doctors like here is Tramadol, here’s Codeine. I’m like I’m not taking that… I just deal with it because I have to… there’s not really any alternative at the moment.	B
P9	I’m just always conscious of everything I do… At work I’m having to think about everything I do all day long, trying to avoid it.	B
P9	If I bend like that (hyperextension), I can feel it loading up pressure on my lower spine, I guess. It doesn’t hurt straight away, after a little while it will start to hurt. But I can feel it’s going to be detrimental, so I just avoid it at all costs.	B
P9	whether it be doctors or chiropractors or whatever telling me to, to be careful with everything I do, but probably Dr. Google's done a bit of it too I suppose.	B
P10	(I’m scared) that I won’t get better… That I won't be able to walk properly again, or I’ll be stuck in a life of just pain… I can’t work and I need to be able to work because I have no money… I hate that my back is like f**king me up so much and I’m only just trying to make a new life in Australia… And I’m young and I don’t like that this is all happening when I'm so young.	B
P11	In the first one year to two years, I just wouldn’t do any at all, I wouldn’t help, I wouldn’t do anything because I’d be so scared of setting off those little triggers of pain instances but yeah, I just wouldn’t do them, I’d avoid them.	B
P11	It’s just little things like bending down to stop Bailey (the dog) from running off even then I’m cradling my back like I try and go down with my whole back; I don’t just try and go down with one section of my back. Beforehand, I’d just go in. I had such bad posture…	B
P11	Lying down, it’s like after all day of standing on my feet even going to lay on the couch, I describe it to my girlfriend as it’s like kind of just a euphoric rush that it’s just like your body feels relaxed and all the bad energy is drained… basically the pain is I could say is gone basically.	B
P12	I understand now I think that it was clenched as an automatic method of doing what I thought it should be doing to protect my back.	FU
P12	I'll hesitate for a minute to think about how I'm going to do it without causing too much trauma. So, I don't do things without thinking and other cautions.	B

Participant and quote		Interview B = baseline FU = Follow-up
Theme 3: Conscious non-protection (Strong follow-up theme)		
P2	If I've got pain, I'm trying to move exactly how I would without pain… Relaxed, fluid. Just move fluidly… (and now I'm) moving better, it's more free flowing, without hesitation.	FU
P2	One of the biggest things… is I try and relax... more. Sometimes I'll find that the fact that I'm starting to get a bit sore and that is because I'm tense, I'm too tense.	FU
P3	KW: How do you feel in your back now? P3: Um yeh better. A lot looser because I've been taught to use your stomach and breathe more through your stomach.	FU
P3	(Now I try to) round my back… (and it feels) better… (which surprises me) a little…because you're always being told to keep your back straight, boobies out… (and) I've had pain in my back (when I tried doing that).	FU
P4	(Response to pain) would be nowhere near what I did before in terms of avoiding movements and lying down and being passive, I guess I would, yeah, I'd be more active and get warmer and move more. I would say move more would be the key thing.	FU
P5	KW: When you say you think before you leap, what are you thinking about? P5: Oh, the breathing and relaxing, you know, just not that tension. Try and reduce the tension in your body…the breathing is the key. No doubt about that. I think that the body tension that I've got, it's (breathing) reduced that well and truly it's, it must've done, I'd like to have somebody do a measure of my body tension, because I would think my body tension has gone down by about half, easily.	FU
P5	P5: Most certainly. There's no, there's less tension there than there was before. Some of the tension before I created myself. KW: How? P5: By bracing, breathing in and tensing the muscles up before I tried anything. I think that made it worse. KW: Why did you do that? P5: That's what we were told to do before.	FU
P5	P5: The old way in the past I was always taught to, if you go to do something and your back is sore, you brace yourself. In other words, you tense yourself up. And then attempt to do what you wanted to do. KW: What do you think of that now? P5: Oh nonsense.	FU
P6	I think breathing really helps. When I breathe in, I can imagine my back stretching it out. Like, you know how when you massage someone, you push out the knots externally, but it feels like when I breathe, I'm stretching it from the inside. And in a sense, I'm massaging on the insight where the deep muscles are. So, in a way, it kind of loosens the muscles on the inside.	FU
P6	And then as soon as I breathe in, take deep breathe in and out and just picturing my back, just letting go of all that tension. And then the pain mostly goes away now.	FU
P7	Because if I was in pain, I used to like stop doing things whereas now I like to stretch it out or meditate or whatever or breathe, I just do things. I don't just rest. I do rest as well. But I have more movement than I do rest. Whereas before it just like, it was full rest doing nothing and just seizing up.	FU

Participant and quote		Interview B = baseline FU = Follow-up
P7	A lot of mine is breathing and just relaxing. Whereas obviously, I was quite tense before. But now most of my pain relief is from breathing, which is weird because you do that all the time. But it's a different kind of breathing… it relaxes your body. It relaxes your muscles that are tense and are giving you pain.	FU
P7	Because I was like holding my breath every time, I'd go down to pick something up or something like that, which now I don't, I breathe, which is totally weird that you think that you don't breathe but you actually don't. Well, I didn't. And I didn't even realize I wasn't doing it. But now I do. And that helps a lot.	FU
P8	My back in the initial weeks, well, it was, it didn't make a remarkable improvement at first, until I sort of got my head around just relaxing and doing the deep breathing and also believing that it's not going to injure anything. To trust it.	FU
P8	It actually feels really good. So, I'm not afraid to bend. I'm not afraid to pick up things off the floor. Yeah.	FU
P9	I just assumed it was worn out but what this is telling me is that it's clearly not. It seems to be functioning alright.	FU
P9	I'm still doing the exact same bad habits when I'm not thinking about it. So, for me, it's trying to just make them second nature, I guess… So, I need to try and be conscious again, getting my breathing better, but I'm certainly getting there.	FU
P10	KW: How much control do you feel like you have over your pain now? P10: Like an 8 or a 9 out of 10. KW: Wow. And what was it before? P10: Zero.	FU
P10	I'm not standing up straight, like a board, and just more relaxed in how I stand, and I'm not always as tense and anxious and stuff… Learning to relax my back... that was Yeah, I think that's the thing that really helped.	FU
P11	I'd say at least 90% (control) and the last 10% is just getting that last amount of everything like the drugs I'm on and that sort of stuff, that's the last 10% and the last thought process around more understanding…	FU
P12	KW: How did you get to the stage of knowing not to protect, not to tense? P12: Um, it was just two things. Being able to do things which normally would cause a feeling of trauma and have them not do that if there's an antidote and having a lot of new information about what is really going on and not going on in my back, which is completely different to what I thought. So those two things would have probably told muscle brain to do something else. Because it had not only a little bit of academic information, but also hard evidence that doing a bad thing followed by another thing, breaks the cycle.	FU
P12	I've completely recovered but I'm continuing to exercise or exercising the option to stay completely recovered by flexing and doing things which I now think are good for the whole lower back area, which is in my case, lots of looseness.	FU
P12	But the main was choosing to do things that will aggravate the pain and having an antidote ready, and in my case the antidote started being get on the exercise bike, get on a bike. And that turned out to be an effective antidote, so I was able to do things	FU

	Participant and quote	Interview B = baseline FU = Follow-up
	which would normally, reliably, cause me great stress and back pain.	
Theme 4: nonconscious non-protection (strong follow-up theme)		
P1	I feel nice and relaxed. No pain, hello, no pain. Terrific.	B
P1	KW: Do you find it easy to relax your back? P1: Sitting here is not a problem, lying in bed's no problem but you can't relax when you're standing or walking, can you? So, what other position are you going to relax in? KW: Bending or any other activities? P1: Bending is not relaxing because it hurts!	B
P2	And confident in movement of course, and picking up the kids… Pick one up, one side, one up the other, don't even think about it… I'm moving better. It's more free flowing, without any hesitation… So, it's a whole different mindset now… I don't even worry about it. So yeah, totally different to before.	FU
P3	KW: Would you say you still avoid bending? P3: No, I bend more probably. Because I, yeh, I roll into it and... I don't even think about it now.	FU
P4	I was someone who would be very um very afraid of certain movement patterns because I felt like my body was fragile and my back was fragile, and it could only move in a certain way. Otherwise, I would be injured, and I would be afraid of um bending over. Um, I'd be afraid of unnatural, movement, I'd be afraid of surprises in terms of movement patterns. If someone jumped out at me or a sneeze came on, I'd be afraid of that. Um, what changed it all was confronting my biggest fear in terms of allowing myself to be in what I perceived to be a fragile position, a vulnerable position, um, which was basically hunched over and bent over and having a rounded back, not only having a rounded back, which was a big fear of mine, but holding a heavy load under a rounded back. Um, the fact that I had to do it. Um, and did it successfully and progressively add weight each time, bit by bit. Um, yeah, the fact that I did that and didn't get hurt at all just made me throw out everything I thought I knew about my pain, about um, the, the strength of or weakness of my back. So having done that, um, that was worst case scenario, having gone through it, there's really nothing I am afraid of anymore because that was it, that was, that was what I was afraid of. And um, now that I've gone through it, there's... Every other movement is a safe movement in comparison. And if that movement was completely safe then to me logically, everything else is safe.	FU
P4	Even if it's a, um, a, um, max Rep, I'm not thinking about, oh, how's my back looking? How's it, is straight enough? Is, you know, is everything locked in now? It's just about trusting my back will lock in as much as I need it to. I don't have to do anything. It's just going to happen. It's not gonna, it's not gonna fail me. I don't think my back going to fail me anymore.	FU
P4	P4: Not, not because I'm necessarily thinking about rounding my back anymore. I guess I'm at first, I was trying to retrain myself to allow myself to, to arch, but now I just move, however my, um, you know, my body wants to move without fear.	FU
P6	And then in a sense, I was able to stretch it out unconsciously to loosen.	FU

Participant and quote		Interview B = baseline FU = Follow-up
P6	And then eventually keep my mind off the sore back and allow the back to loosen by itself I guess.	FU
P7	P7: I don't know. I know I move a lot, just to keep it going. Does that make sense? Um, but probably I wouldn't be like relaxed sitting. KW: Did you used to be? P7: Yeh I used to be able to relax, sitting down, like slouch in the chair or, you know, sit comfortably in a chair. I can't do that. I have to constantly move. KW: You don't feel like you can relax in a chair? P7: No, I have to constantly move to sit in a chair. Um, otherwise my back seizes, or my butt seizes, one of the two.	B
P8	It actually feels really good. I'm not afraid to bend. I'm not afraid to pick up things off the floor… even my moods improved a lot more. It's, I'm more happier.	FU
P8	Well because I wasn't moving very freely, I was just holding and just like it, just maintain the muscles not to move. So hence it just increased the pain.	FU
P10	I'm doing that now instead of doing the old way that I used to walk, and I don't have to think about it, I just kind of do it.	FU
P11	I think now my muscles are a lot more tight than they would've been beforehand. My buttocks is always tight and my girlfriend has told me that that might be in relation to my back and all that sort of stuff to get massages in there, but it goes from…I get a massage and then it goes from being tight to being a little less tight but then it goes really tight again after a period of probably a day or so.	B
P11	Now, yeah, I don't even like think about it. I don't even think about what's the best way to pick this up or what is the best way I've been told to pick this up. Now I just do it… (Before, I'd be) bending my knees, keeping my back straight, trying to pick it up 'correctly', now I don't give a fuck.	FU
P12	I think when I'm, so when I have a lumbar roll or something like that in place, they're loose and relaxed and happy. But at other times they're tense… Yeah. When I get myself positioned with back support, I am completely relaxed and forget about, I don't have any back pain even though if I was to go how's my back feeling, I noticed that it's hurting. But then if I get back to whatever I'm trying to think about I don't have any back pain.	B
P12	But the big ones, which were the nasty curved back bending, they don't cause pain anymore. Although, I still actually am doing those other antidote-like activities. So, if I just stopped everything else and only did lifting, there's an untested possibility that that would return – but I don't think that would return. I think I'm completely cured.	FU
P12	I have an idea that I don't need to have control, that it will just look after itself. So, I don't have to do anything, so I've got control, but I don't need it.	FU
P12	The emotional pain that I was having, which I do imagine was one of the factors, which has also now dissolved. Well, it's dissolved because of the boat, I reckon, entirely because of the boat KW Because you're not living with your daughter anymore? P12 Well that's certainly a small help, but the biggest part is just that I'm not employed, so I don't have to sit still and use my	FU

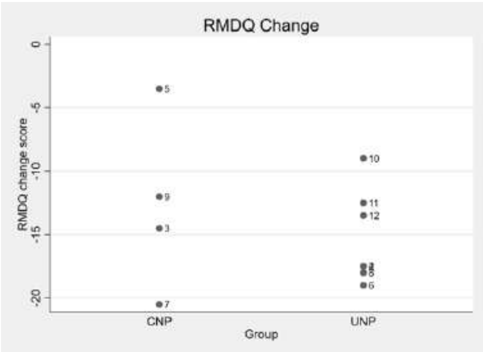
Participant and quote		Interview B = baseline FU = Follow-up
	brain and try not to have cry breaks – I'm having to clamber around. There's no mental work, it's all physical KW So that's lifted the depression and sadness P12 Yeah. In order to feel sad, you have to be sat still.	

6.13.5 Appendix 5. Graphs of additional analysis

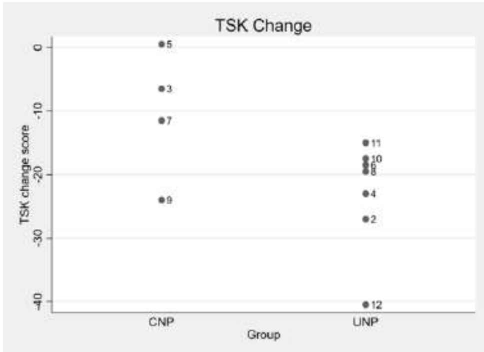
Figure 6-6 Appendix 5. Graphs of additional analysis. Mixed methods

Graphs of the change in outcome measures for participants in the conscious non-protection (CNP) and unconscious/nonconscious non-protection (UNP) groups following the post-intervention qualitative interview.

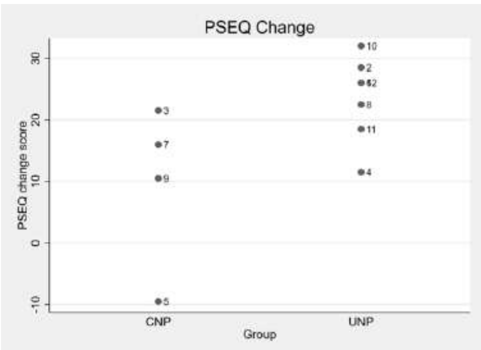
a) Roland Morris Disability Questionnaire



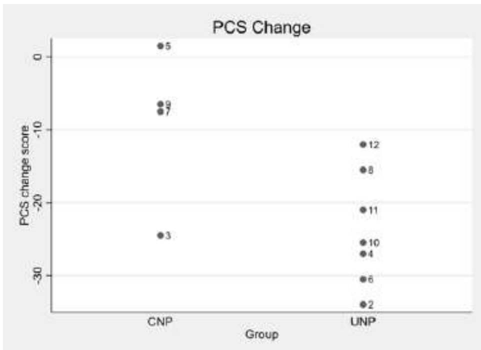
b) Tampa Scale of Kinesiophobia



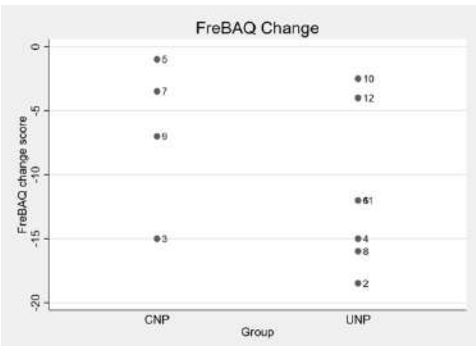
c) Pain Self-Efficacy Questionnaire



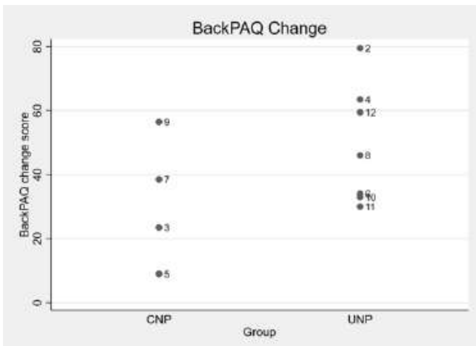
d) Pain Catastrophising Scale



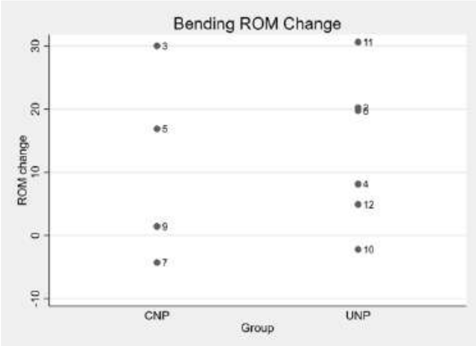
e) Fremantle Back Awareness Questionnaire



f) Back Pain Attitudes Questionnaire



g) Bending Range of Motion



h) Bending Speed

Chapter 7 Discussion of thesis

The main aims of this thesis were to; a) review the currently available evidence regarding the relationship between changes in movement and changes in LBP or activity limitation among *cohort studies* and *RCTs*, b) review the currently available evidence regarding the relationship between changes in movement and changes in LBP or activity limitation among *single-case designs*, c) investigate the relationship between movement, posture, and LBP using a repeated measures single-case series, and d) understand how people with persistent, disabling LBP conceptualise the relationship between movement, posture, and their LBP before and after rehabilitation; integrating qualitative and quantitative findings. Table 7.1 tabulates the main research questions asked in each chapter, with a brief indication of the novel contributions for each question.

This chapter discusses the main findings of this thesis through the notion of a 'LBP schema' that encompasses movement and posture. This schema, and how it shifts as LBP improves, will be viewed through the lens of the Common Sense Model. The chapter concludes by describing the strengths and limitations of this body of work, possible future research directions, and the closing remarks.

Table 7.1 A summary of research questions asked and the contributions made by each chapter.

Research Question		What was known	What this research adds
Chapter 3 – Systematic review: Cohort studies and RCTs			
3a	How frequently are changes in spinal movement related to changes in pain or activity limitation at the individual level in people with LBP among cohort studies and RCTs?	Group level (mean) changes in movement infrequently relate to group level (mean) changes in pain or activity limitation. No systematic reviews had previously comprehensively investigated individual level (correlation) change scores.	The systematic review found low-quality evidence from 27 studies involving 2,739 participants that changes in spinal movement infrequently (31% of the time) related to changes in pain or activity limitation at the individual level. The restricted ability of the included studies to accommodate patient heterogeneity was a key limitation when answering this research question.

Research Question		What was known	What this research adds
3b	How does movement change if it is related to LBP changing among cohort studies and RCTs?	Unknown	The systematic review found that when changes in movement were related to changes in pain or activity limitation, almost always (93% of the time), spinal movement range increased, got faster, or more relaxed (greater flexion relaxation) as LBP improved. We termed these movement changes as ‘less protective’.
Chapter 4 – Systematic review: Single-case designs			
4a	How frequently are changes in movement related to changes in pain or activity limitation at the individual level in people with LBP among single-case designs that can more readily accommodate patient heterogeneity?	Unknown	This systematic review found low-quality evidence from 23 studies involving 33 participants that changes in movement frequently (68% of the time) relate to changes in pain or activity limitation.
4b	How does movement change if it is related to LBP changing among single-case designs?	Unknown	The systematic review found that when changes in movement were related to changes in pain or activity limitation, almost always (97% of the time), spinal movement became ‘less protective’ (greater range, faster, or more relaxed) as LBP improved.
Chapter 5 – Repeated measures single-case series in 12 people with persistent, disabling LBP			
5a	In 12 people with persistent, disabling LBP, how frequently do changes in individualised movement or posture relate to changes in pain or activity limitation, when using up to 20 repeated measures?	Chapters 3 and 4 indicate that when considering individualised movement assessment and intervention, changes are more frequently observed. However, included studies were of low overall quality and usually only captured pre- and post-intervention measures.	Ten out of 12 (83%) participants demonstrated strong relationships between changes in individualised movement or posture, and changes in pain or activity limitation. Most of the relationships investigated (74% or 61 out of 82) identified a relationship.
5b	How does movement or posture change if it is related to LBP changing?	Chapters 3 and 4 demonstrated that when related, movement	Similar to Chapters 3 and 4, when accommodating patient heterogeneity and utilising repeated measures, movement and posture consistently (93% of the time) became ‘less protective’ as LBP improved

Research Question		What was known	What this research adds
		consistently became ‘less protective’ as LBP improved.	(greater range, faster, more relaxed, or greater posterior-pelvic-tilt during sitting and standing).
Chapter 6 – Mixed Methods study in 12 people with persistent, disabling LBP			
6a	How do 12 people with persisting, disabling LBP *conceptualise* the relationship between movement, posture, and their LBP?	Unknown. Tangential research had demonstrated strong ‘damage’ and ‘fragility’ narratives in musculoskeletal pain. Some research reported protective or avoidance patterns.	People with persisting, disabling LBP described lived experiences of tight, tense, stiff and locked up movement and posture. They reported conscious efforts to be careful, cautious, guarded and protective with their body, believing that pain with movement means they’re damaging their back and that they must follow movement and postural ‘rules’ governed by society and previous healthcare practitioners. The experience was frightening, frustrating, and depressing due to worry and uncertainty about their pain, function, and future.
6b	How does this *conceptualisation* change following a 12-week Cognitive Functional Therapy intervention?	Unknown. Some research had showed that ‘moving freely’, producing ‘relaxed and efficient’ movement, and the development of a biopsychosocial understanding were an important aspect of recovery in people with LBP.	Using cognitive and behavioural strategies to reduce protection (such as reconceptualising their pain, relaxing, breathing, or moving freely), most participants reported reduced pain during pain provocative tasks, increasing their sense of control. This process provided powerful learnings and helped them re-conceptualise movement and posture from threatening, to therapeutic. For some, ‘conscious non-protection’ gave them control over their condition, but the majority returned to ‘nonconscious non-protection’, no longer thinking about their movement or posture, and just living.
6c	How does this *conceptualisation* relate to changes in objective movement, posture, pain, activity limitation, and psychological factors (pain-related cognitions and emotions)?	Unknown.	While there was significant intra- and inter-subject diversity, qualitative changes were largely supported by quantitative changes in movement, posture, pain, activity limitation, and psychological factors. Further, exploratory analysis indicated that changes in pain-catastrophising and pain self-efficacy distinguished the ‘conscious non-protection’ group from the ‘nonconscious non-protection’ group. While there was an indication that changes in other factors (such as movement and LBP beliefs) were also differentiating, these were not significant.

7.1 Relationships are more common when heterogeneity is accommodated

A different prevalence of relationships between changes in movement and changes in pain or activity limitation was found among the two systematic reviews and the single-case series presented in this thesis. The systematic review of cohort studies and RCTs (Chapter 3) identified low quality evidence of a relationship 31% of the time (20 of the 65 times investigated within 27 studies) (Wernli, Tan, et al., 2020). The infrequent identification of a relationship is congruent with similar previous reviews that also often did not identify a relationship (Laird et al., 2012; Steiger et al., 2012). The systematic review of single-case designs (Chapter 4) identified low-quality evidence of a relationship more frequently (68% or 58 out of the 84 times investigated) (Wernli et al., 2021 (in press)). The more frequent relationship observed may have been due to the ability of the single-case designs to accommodate heterogeneity. Other factors, such as selection bias or observational bias due to unblinded assessment in single-case designs, may have also influenced the increased frequency that a relationship was identified. Relationships were even more frequent in Chapter 5 when measurement heterogeneity was combined with a multidimensional, individualised intervention that has demonstrated large effect sizes (Vibe Fersum et al., 2019). In the single-case series (Chapter 5), strong relationships were identified in 10 out of 12 people with persistent, disabling LBP, with an overall frequency of 74% (61 relationships identified out of 82 investigations) (Wernli, O'Sullivan, et al., 2020). In summary, it appears that the more heterogeneity is accommodated, the more frequently a relationship is identified. However, there are multiple factors that may influence the identification of a relationship between changes in clinically relevant patient attributes.

7.1.1 Factors influencing the identification of a relationship

7.1.1.1 Using group-level analyses

One factor that may influence the identification of a relationship is the use of group-level or individual-level analyses. Identifying if a mean change in movement of a group of people with LBP relates to (or, more accurately, 'co-occurs with') a change in their mean pain levels does not necessarily reflect a relationship at an individual level. For example, using group-level analyses can result in the identification of a group-level co-occurrence when there is no individual-level relationship (a false positive). Falsely identifying a group-level co-occurrence in the absence of an individual-level relationship may occur if the people that change in their movement parameters are not the same people that change in pain. In that instance, the groups' mean movement and pain would both change (and therefore co-occur), but at the individual-level, when a person's movement changed, their pain did not (and vice-versa). Conversely, group-level analyses hypothetically could result in no group-level relationship when in reality an individual-level relationship is present (a false negative). For example, if pain and movement both change positively in a third of the group, neither pain or movement changed in another third, and both change negatively in the final third, then the mean of change in movement and the mean of change in pain would not shift (provided the magnitude of positive and negative changes were equal). In this instance where sample variability results in no overall change, no co-occurrence (or 'group-level relationship') would be identified when in reality a (potentially strong) *individual-level* relationship exists. The counteracting influences of positive and negative changes (also known as 'wash out') has been described previously (Dankaerts & O'Sullivan, 2011).

7.1.1.2 Limited ability to individualise assessment

Another potential factor influencing the identification of a relationship relates to a lack of individualised *assessment* of movement. Given the heterogeneity of LBP (Hartvigsen et al., 2018; Maher et al., 2017), and the variable movements, postures, and activities that people with LBP report as problematic (Mitchell et al., 2010), measuring the same movement in all participants may result in investigations of movements that are not actually problematic for certain individuals. This likely influenced the infrequent relationships identified in the Steiger et al. (2012) systematic review, as well as the systematic review of cohort studies and RCTs presented in Chapter 3 (Wernli, Tan, et al., 2020). Indeed, the inability to accommodate movement heterogeneity influenced the indirectness domain of our GRADE assessment for the systematic review in Chapter 3, contributing to the low overall quality of evidence.

7.1.1.3 Limited ability to create change

A third factor that may influence the identification of a quantitative relationship between changes in movement or posture, and changes in pain or activity limitation relates to a limited ability to create change in those factors. If interventions aimed at improving pain or activity limitation, or changing movement or posture, are not able to create sufficient change, then the ability to investigate a relationship between changes in one variable compared to changes in another is limited.

In Chapter 5, we conducted an additional analysis that provided an indication about whether pain or activity limitation improved for each participant. This analysis used a series of simulation models comparing the vector of the baseline phase data points to the combined intervention and follow-up phase vector for pain and activity limitation. It indicated that for the majority, pain or activity limitation improved (see 5.8.2). For many, large shifts in pain or activity limitation were observed. That most participants experienced a significant change suggests we had an intervention that was effective at creating change, thereby allowing the valid investigation of longitudinal relationships between factors if relationships were to be present.

7.1.1.4 Movement or posture may not be related for all people

A fourth consideration when investigating individual-level relationships is that movement or posture may not be relevant for all people with LBP. In the single-case series presented in Chapter 5, two participants (P1 and P10) demonstrated no strong relationships between changes in individually relevant movement or posture, and changes in pain or activity limitation. Visual analysis of plots in Figures 4b, 4d, and 4j of Section 5.4, as well as observation of the results tables and radar graphs in Appendix 2 of Chapter 5 (Section 5.8.2) and Appendix 3 of Chapter 6 (Section 6.13.3) suggest a number of possibilities. It could be that; a) P1 and P10's movement or posture did not change, b) their movement was already 'normal' at baseline and not a salient contributing factor in their presentation (P1's bending ROM at baseline was already amongst the largest of the whole cohort across the whole study and demonstrated minimal change), c) the movement or postural parameters measured were not the salient movement parameters for the person and other parameters *would* show a relationship, d) the tools used to measure movement or posture were not sensitive or specific enough to detect change (for example limited ability to capture EMG, intra-lumbar measures, or whole-body kinematics), or e) a combination of those factors.

As discussed in the literature review (see Section 2.2.3) and in the discussion of Chapter 3 (see Section 3.5), previous literature has identified a group of people that appear to move 'normally' despite their back pain. A Latent Class Analysis of forward bending kinematics and EMG parameters in 266 people with and without LBP identified that 26% of people had LBP in the subgroup the authors named the ‘standard’ movement pattern group (n = 133) (Laird et al., 2018). This highlights that a small group of people with LBP appear to move normally despite their symptoms. If this is the case, an individual-level investigation into the relationship between changes in movement and changes in pain or activity limitation is unlikely to show an association for those people.

In summary, the increasing frequency of a relationship between changes in movement or posture, and changes in pain or activity limitation (31%, 68%, and 74% in the cohort study or RCT systematic review, single-case design systematic review, and single-case series respectively) may reflect that as individual heterogeneity is accommodated, relationships are more frequent. Additionally, more effective treatments may make the observation of a change relationship more likely. The results of this thesis about the frequency of a relationship attempted to address current limitations in the literature. Firstly, by systematically reviewing *individual-level* relationships across multiple movement parameters in Chapter 3. Secondly, Chapter 4 addressed the limitation of a lack of *individualised assessment* identified in Chapter 3 by performing a systematic review of the single-case design literature. Finally, the single-case series in Chapter 5 presents a study using repeated measures of individualised movements and postures in an attempt to address the limitations of the existing low-quality evidence. We used an assessor blind to clinical outcome data, up to 20 repeated measures over 22 weeks, and an individualised intervention with demonstrated efficacy. In this way, Chapter 5 represents an attempt to rigorously answer the question of ‘how frequently is a change in person-specific movement or posture related to a change in pain or activity limitation at the individual level in people with LBP?’ The findings suggest relationships are present most of the time (approximately 70-80%). However, this is evidence of association only, and occurred in the context of 12 people receiving Cognitive Functional Therapy. Further research in larger populations and using different interventions would provide important insights into how generalisable those findings are.

7.2 Embodiment of a ‘protect your damaged back’ schema in people with LBP

A person’s *schema* can be defined as the way they make sense of a construct based on a pre-existing understanding formed by beliefs, memories, emotions, cognitions, experiences, and cultural exposures that together, guide their behaviour (Banaji & Greenwald, 2013; Peebles & Moore, 2000). This process is fluid and constantly updated through information that is heard (for example from the media, family, or clinicians), observed (for example through vicarious experiences of friends or family), and felt (for example via somatic bodily sensations) (Banaji & Greenwald, 2013). From a neurobiological perspective, it is a process that likely occurs through neural networks and cortical matrixes acting as continuous feedback loops modulating interactions of the neuro-immune-endocrine systems (Brodal, 2017; Wallwork et al., 2016).

The concept of a ‘pain schema’ has been reported by Caneiro et al. (2019) following the observation of concomitant rather than sequential changes in multiple proposed mediators (such as pain control and kinesiophobia) and outcomes in a single-case experimental design. That study investigated the process of change in four people with persistent, disabling non-specific LBP and high pain-related fear undergoing a CFT intervention (Caneiro et al., 2019). Concomitant changes to multidimensional factors led to the authors suggesting a ‘pain schema disruption’ (Caneiro et al., 2019), implying the presence of an old pain schema and a new pain schema.

In the baseline qualitative interviews reported in Chapter 6, people with LBP commonly discussed experiences of stiff, tense, and restricted movements or postures. Similar reports of restricted movements have been described previously among people with LBP (Pugh & Williams, 2014) and may be reflective of a nonconscious protective response secondary to fear (of movement/damage) or the belief of structural damage (Caneiro et al., 2020; Christe, Crombez, et al., 2021; O’Sullivan et al., 2018). Guarded, tense, and restrictive patterns may also be an automatic response to the experience of pain (Arendt-Nielsen et al., 1996; Dubois et al., 2011; Graven-Nielsen et al., 1997; Jacobs et al., 2011; Wong et al., 2016). Participants also commonly reported *conscious* attempts to protect their back, either through the avoidance of threatening tasks, or through ‘protective’ movement patterns that followed traditional movement and posture rules frequently taught to them by healthcare practitioners. Previous research has similarly reported that people with LBP hold beliefs that movement and posture must be ‘proper’, and that painful activities must be avoided to protect the back from further damage (Bunzli, Smith, Schütze, et al., 2015; Bunzli et al., 2013; Darlow et al., 2015). Together, the findings from the baseline qualitative interviews presented in Chapter 6 combined with previous similar literature, suggests the presence of a ‘protect your damaged back’ schema in people with LBP.

Consistent with the qualitative reports of stiff, restricted, and protective movements and postures from the 12 people with LBP in Chapter 6, quantitative measures of movement and posture at baseline also demonstrated protective patterns. Compared to follow-up, movement was commonly slower, restricted (less ROM), and more guarded or tense at baseline, while postures were frequently in more anterior pelvic tilt (suggestive of more lordosis). Similarly, the more relaxed, less protective movements related to LBP improvement that were commonly seen in the systematic reviews (Chapters 3 and 4) further suggest shift from a baseline protective pattern. Findings of protective patterns at baseline are consistent with the protective movement patterns previously identified among people with LBP (Dankaerts et al., 2006b; Geisser et al., 2005; Laird et al., 2014; Nolan, O'Sullivan, et al., 2019). The alignment between the stiff, tense, and protective qualitative reports; the slow, restricted, and guarded quantitative measures; and the previous literature, suggests the *embodiment* of a 'protect your damaged back' schema in the movements and postures of people with LBP.

7.2.1 Factors contributing to the embodiment of a 'protect your damaged back' schema

7.2.1.1 Negative psychological factors

Strong movement and postural beliefs were reported at baseline among the participants in the mixed methods study presented in Chapter 6. The participants commonly believed that they had to move and posture themselves in careful and cautious ways to protect structures they thought, and were told, were damaged. Indeed, negative LBP beliefs were common as measured by the BackPAQ in the self-report quantitative measures, reflecting those qualitative findings. Similarly, the participants also frequently described significant fear of movement, particularly without protection, as well as fear of further damage or (re)injury, findings supported by elevated TSK scores and in line with previous literature (Bunzli, Smith, Watkins, et al., 2015). In addition to negative LBP beliefs and elevated kinesiophobia, heightened pain catastrophising and reduced pain-self efficacy were also commonly present at baseline as measured by the PCS and the PSEQ in the self-report questionnaires, as were altered body perceptions measured by the FreBAQ. These finding suggest that the protective movement and postures representative of an embodied 'protect your damaged back' schema are associated with negative pain-related cognitive and emotional factors.

The negative psychological factors commonly reported in the mixed methods study in Chapter 6 align with previous reports in people with LBP (Bunzli, Smith, Schütze, et al., 2015; Bunzli et al., 2013; Burton et al., 1995; Pincus et al., 2002; Toye et al., 2013). The reports of threatening health information during encounters with clinicians contributing to these negative psychological factors also aligns with previous literature (Christe, Nzamba, et al., 2021; Darlow et al., 2015; Setchell et al., 2017). This raises important questions regarding the potential iatrogenic consequences of negative clinician messages for some people with LBP (Lin et al., 2013; Loeser & Sullivan, 1995).

While it appears that negative psychological factors played an important role in the protective movements and postures of the 12 participants presented in Chapter 6, a systematic review and meta-analysis of 52 studies in 2021 identified only a weak association between more negative psychological factors and more protective movement (Christe, Crombez, et al., 2021). This apparent discrepancy may reflect the lack of accommodation for individualised measures of psychological factors and movement. Indeed, the authors recommended future research using more specific and individualised measures of psychological factors, pain intensity, and spinal movement (Christe, Crombez, et al., 2021).

7.2.1.1.1 *Individualised* factors contributing to an embodied ‘protect your damaged back’ schema

To date, there is only weak evidence for the relationship between negative psychological factors and protective movement based on the Christe et al. (2021) systematic review and meta-analysis. However, it appears that the dominant or most important psychological factor varied between individuals in the mixed methods study presented in Chapter 6. As evidenced by the radar graphs presented in Section 6.13.3.3, some participants (such as P9 and P12) displayed high levels of kinesiophobia with pain self-efficacy or pain catastrophising less affected. Other participants (such as P1, P5, and P11) demonstrated lower levels of kinesiophobia but worse pain control. This may suggest that the salient psychological factors that contribute to more protective movement or posture may vary across individuals. Additionally, the way psychological factors interact, both with each other and with other factors such as pain intensity, may also be heterogenous, supporting the presence of a complex system (Brown, 2009). Previous case series have also demonstrated variable patterns of change (Boersma et al., 2004; Caneiro et al., 2019), providing support for the presence of heterogenous recovery pathways. Not only were the dominant psychological factors heterogenous in the participants of the mixed methods study, but protective patterns also appeared person specific, consistent with previous research (Rabey et al., 2017).

Not all participants in Chapter 6 demonstrated slow, reduced, *and* guarded behaviours at baseline. Some participants (for example P1, P4, and P9) demonstrated slow bending movement, but relatively normal bending ROM compared to the whole cohort (including after the intervention). Others, however (for example P10), demonstrated comparatively normal bending speed but reduced ROM. The radar graphs presented in Section 6.13.3.3 provide visual representation of the heterogeneity of the psychological and movement parameters for each participant. Together, these findings may, at least in part, account for the only weak relationships observed between generic measures of psychological factors and spinal movement in the Christe et al. (2021) systematic review. Similarly, only task-specific, and not generic, measures of kinesiophobia were associated with lumbar ROM in a study measuring kinesiophobia and lumbar ROM in 55 people with LBP (Matheve et al., 2019). Individualised relationships further support the multidimensional and heterogenous nature of persistent non-specific LBP (Maher et al., 2017), and support individualised management approaches (Foster et al., 2018; O'Sullivan et al., 2018).

7.2.1.2 Pain itself may contribute to protective movements and postures

There is some evidence that the experience of pain itself may contribute to more protective movement and postural patterns. Experimental pain induced by hypertonic saline injection, noxious heat, or electrocutaneous stimulation has been shown to result in protective, co-contracted, or guarded movement patterns (Arendt-Nielsen et al., 1996; Dubois et al., 2011; Graven-Nielsen et al., 1997; Jacobs et al., 2011; Wong et al., 2016). Additionally, there is some evidence that worse pain intensity is associated with more protective patterns in clinical LBP populations (Laird et al., 2019; Nolan, O'Sullivan, et al., 2019). The 12 participants with disabling LBP in Chapter 5 and Chapter 6 demonstrated a median pain level (Tri.NRS) of 5.75 out of 10 (full range 1.3 to 8.1) during the baseline period. For comparison, the mean baseline pain levels from a range of widely cited trials in individuals with (presented in Section 3.8.4 and 4.9.6) was 4.8 out of 10 (standard deviation of 1.4)), with a median of 5.1 out of 10. This suggests that the participants in our study had comparable or slightly higher pain levels than previous studies. While more pain appears to be associated with more protective patterns in some studies (Laird et al., 2019; Nolan, O'Sullivan, et al., 2019), there was no indication that higher baseline pain or activity limitation levels impacted the identification of a relationship between *changes* in movement and *changes* in pain or activity limitation in the systematic reviews presented in Chapter 3 and Chapter 4 (see 3.8.4 and 4.9.6 for those additional baseline analyses). This suggests that while higher pain might be associated with more protective patterns cross-sectionally, there may be other factors involved in the longitudinal relationship between movement and pain or activity limitation. These other factors may include broader biopsychosocial factors and can be understood through the lens of the Common Sense Model.

7.2.2 'Protect your damaged back' through the lens of the Common Sense Model

The Common Sense Model suggests that contextual, cognitive, and emotional factors continuously interact and influence ongoing behavioural responses (Leventhal et al., 1980). Additionally, appraisals of that behavioural response continuously influence a person's illness representation (Bunzli et al., 2017; Leventhal et al., 1980). Through the lens of the CSM, if a person with LBP experiences (or has memories of) intense pain in their back, has a negative representation of their pain, and experiences negative pain-related emotions, then careful, protective, or avoidant behaviours could be seen as a common sense response (Bunzli et al., 2017). As discussed, participants in the mixed methods study (Chapter 6) commonly reported negative pain-related cognitions and emotions. In the context of those negative psychological factors and high pain intensity, a common sense response of avoidance or protective behaviours could be viewed as a rational and logical attempt to seek safety. Safety seeking behaviours have been previously reported in people with LBP, particularly in those with high health anxiety (Sharp, 2001; Tang et al., 2007). Our findings also add some support to previous literature that questions the purely fear or phobic-based avoidant behaviours proposed by the fear avoidance model (Bunzli et al., 2017; Caneiro et al., 2017).

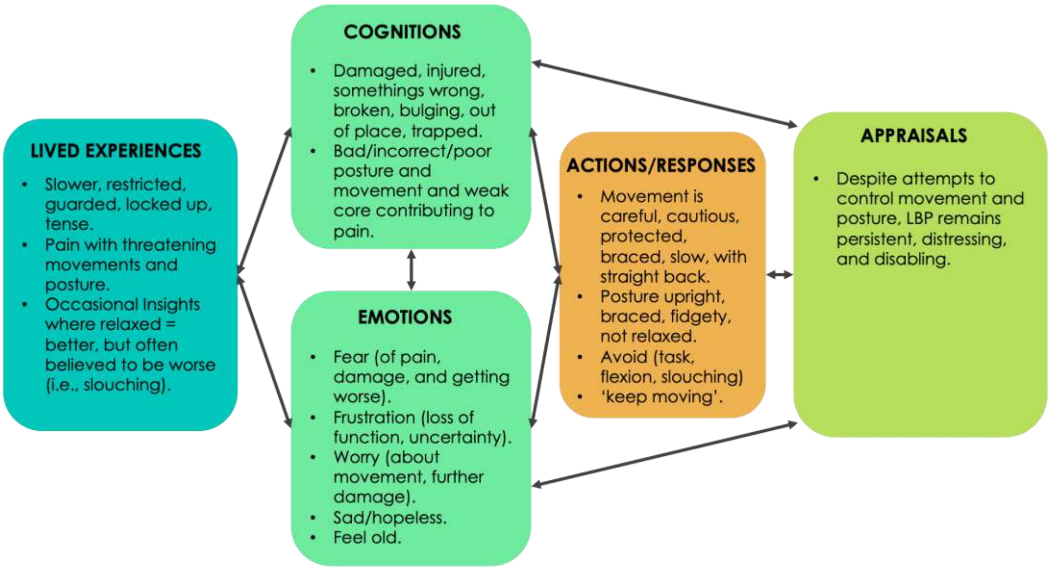
Negative psychological factors contributing to protective patterns may be particularly salient when they originate from encounters with clinicians or are widely accepted among society (Hassan & Barber, 2021; Koch & Zerback, 2013). Indeed, the participants in Chapter 6 commonly reported that their the protective patterns were learnt from, or reinforced by, clinicians and societal messages, a finding consistent with previous literature (Christe, Nzamba, et al., 2021; Darlow et al., 2015; Setchell et al., 2017). So, in addition to negative psychological factors and pain, it appears that healthcare and societal messages further contribute to careful, protective behaviours.

Through the lens of the CSM, if the careful behaviour results in less or no pain, then the action is appraised as successful and helpful, and is therefore maintained (Bunzli et al., 2017; Leventhal et al., 1980). However, in the context of the 12 people in Chapter 6, these 'protective' behavioural responses appeared to be ineffective as evidenced by their persisting disabling LBP at baseline (median RMDQ was 17.5 out of 23, full range 12 to 22) and care-seeking behaviours. Appraisals that a person's coping response is ineffective may result in a complex metacognitive process that reinforces distress, a pattern that is common in people with disabling pain (Schütze et al., 2017).

Based on the reports by the participants, the protective patterns were often maintained despite not being helpful as part of response to negative beliefs, fear, and because they represented a safer alternative than moving without protection. Interestingly, the maintenance of protective behaviours often occurred despite participants commonly reporting experiences of less pain when engaging in less protective, more relaxed strategies. This is exemplified by a quote from participant six who said at baseline: "(sitting upright) *makes it* (my LBP) *worse but I just thought I'm meant to keep my posture upright*". This suggests that for this individual their perceived need for spinal protection transcended experiences of less pain with less protection. This further supports the premise that protective movements and postures represent an attempt to seek safety - an action that appears to be prioritised over contradictory experiences (Sharp, 2001; Tang et al., 2007). Additionally, it further highlights the powerful influence of clinician messages, which has been reported previously (Darlow et al., 2013; Stewart & Loftus, 2018).

In summary, it appears that a complex interplay between numerous individualised psychological factors, the aversive experience of pain, and clinician or societal messages contribute to the *embodiment* of a 'protect your damaged back' schema. This process appears to be a common sense attempt to seek safety. The embodied 'protect your damaged back' schema appears to be characterised by careful, slow, restricted, guarded, and upright movements and postures that follow clinician advice and accepted societal norms (Darlow, Perry, Stanley, et al., 2014; Slater et al., 2019). When these responses are appraised as unhelpful in reducing pain or activity limitation, they likely further perpetuate or amplify a person's distress, reinforcing the negative structural beliefs and protective process. Figure 7-1 represents a visual summary of the embodied ‘protect your damaged back’ schema through the lens of the CSM.

Figure 7-1 Movement and posture forming part of an embodied ‘protect your damaged back’ schema through the lens of the Common Sense Model



7.2.3 Pre-existing ‘protect your back’ beliefs among society

While the ‘protect your damaged back’ schema may become particularly salient in people with LBP, evidence showing implicit and explicit negative LBP beliefs in populations without LBP (Caneiro et al., 2018; Darlow, Perry, Stanley, et al., 2014; Horgan et al., 2020; Nolan et al., 2021) suggests that aspects of a ‘protect your back’ schema may be common in the general population worldwide. Similarly, negative psychological factors among people without LBP have been associated with more protective movement (Knechtle et al., 2021; Trost et al., 2012), showing the potential importance of pre-existing negative psychological factors in protective strategies. It is possible that when the somatic experience of pain in the lower back accompanies a ‘dormant’ or ‘background’ ‘protect your back’ schema, it is strengthened and evolves into a ‘protect your *damaged* back’ schema, particularly if the LBP does not resolve. While speculative, this may in part be secondary to current societal and healthcare contexts that portray pain (particularly LBP) in a dominantly negative light.

7.2.4 Potential pain mechanisms of the embodied 'protect your damaged back' schema

This thesis identified protective movement and postural patterns in people with LBP that is congruent with existing literature (Dankaerts et al., 2006b; Geisser et al., 2005; Laird et al., 2014; Nolan, O'Sullivan, et al., 2019). These were; a) directly observed at baseline in the participants presented in Chapter 5 and Chapter 6, and b) indirectly observed given the shift towards less protective movement in people whose LBP improved as presented in Chapter 3 and Chapter 4. We also identified strong negative psychological factors in the mixed methods study presented in Chapter 6 that are consistent with previous studies of LBP populations (Bunzli, Smith, Schütze, et al., 2015; Bunzli et al., 2013; Burton et al., 1995; Pincus et al., 2002; Toye et al., 2013). In the consideration of these findings, it is postulated that an embodied 'protect your damaged back' schema may contribute to a person's pain experience through the activation of cortical matrixes or neuronal networks associated with the perception of threat and danger (Brodal, 2017; Wallwork et al., 2016). Protective movements and postures (slow, restricted, and guarded patterns) that may in themselves be pro-nociceptive (O'Sullivan et al., 2018), likely contribute to these cortical matrixes and neuronal networks. When strategies that attempt to reduce pain or activity limitation fail, a cycle of further pain sensitisation, distress, disability, and protection ensues (Schütze et al., 2017).

In summary, it is likely that a heterogenous interplay between cognitive, emotional, pain, neurobiological, societal and social messaging, and contextual factors contribute to the protective movement and postural patterns observed in people with LBP (Brodal, 2017; Christe, Crombez, et al., 2021; Wallwork et al., 2016). This multidimensional, nonlinear process provides support for understanding persistent LBP as a complex adaptive system, characterised by relationships, patterns, and constant adaptation (Brown, 2009; Guccione et al., 2018). Through the lens of the CSM, protective movement and posture may represent a common sense response to a painful and threatening experience accompanied by 'damage' beliefs and negative psychological factors. While this response may represent an attempt to seek safety and is perceived as a better alternative to the threatening prospect of moving without protection, the findings from the mixed methods study presented in Chapter 6 suggest this response is largely unhelpful, given participants at baseline were still highly disabled by their pain. Consistent findings of less protective movement when related to LBP improvement in Chapters 3, 4, and 5 further support the premise that a protective response may actually be over-protective and unhelpful among many people with persistent non-specific LBP, however higher quality research is needed. In the next section, the role of movement and posture as LBP improves will be discussed.

7.3 The role of movement and posture as LBP improves

While there was significant heterogeneity amongst the studies included in the systematic reviews presented in Chapters 3 and 4, as well as significant heterogeneity among the 12 people with persistent, disabling non-specific LBP in Chapters 5 and 6, there was one relatively homogenous and consistent finding across this body of work. When a relationship was observed, movement (or posture) almost always returned towards being *less protective* when related to LBP improvement. That is, spinal movement range increased, became faster, or more relaxed during bending or lifting, while pelvic slumping commonly increased during sitting or standing. Less protective movement as pain or activity limitation improved was observed in 93% of the relationships in the systematic review of cohort studies and RCTs presented in Chapter 3 (Wernli, Tan, et al., 2020) and 97% of the relationships in the systematic review of single-case designs in Chapter 4 (Wernli et al., 2021 (in press)). In the single-case series presented in Chapter 5, less protective movement and posture as pain or activity limitation improved was observed in 93% of the relationships (Wernli, O'Sullivan, et al., 2020). Accordingly, in cases where a relationship was *not* observed (69%, 32%, and 26% of the time in Chapters 3, 4, and 5 respectively), it is possible that movement (or posture), pain or activity limitation may or may not have each changed but there was no relationship.

The consistent findings of less protective movement or posture when related to pain or activity limitation improvement suggests a transition away from the embodied 'protect your damaged back' schema as people with LBP improve. This is supported by the quantitative shift in beliefs, emotions, and behaviours observed in 11 of the 12 people with LBP described in Chapter 6 (see Table 6.2 Joint display table and Chapter 6, Appendix 3, Section 6.13.3.2). Qualitative reports of 'no longer believing that their back is damaged and needs protecting' further supports the dis-embodiment of a 'protect your damaged back' schema (see 6.4.1.2 and 6.13.4 for supporting quotes). Additionally, less protective patterns found in people without LBP in multiple systematic reviews comparing kinematics and EMG of people with and without LBP provides additional support for the transition away from an embodied 'protect your damage back' schema and towards movements and postures that resemble people without LBP (Geisser et al., 2005; Laird et al., 2014; Nolan, O'Sullivan, et al., 2019). While there was nuance to the journeys reported at follow-up by the participants in Chapter 6, there were common themes that provide important insights into the role of movement and posture as LBP improves.

7.3.1 The adoption of a new 'movement is safe' schema

During the follow-up interviews after the CFT intervention, nearly all (11 out of 12) participants described how less protective movement and postural strategies (muscle relaxation, slow breathing, and fluid movements) helped them reduce their pain. Contrary to their expectations of *more* pain and perceived damage during threatening tasks they thought required protection, experiences of *less* or *no* pain while performing these activities in a less protective way often came as a surprise. Under the guidance of a trusted clinician and accompanied with personalised education about their LBP condition, these experiences made many participants question what they thought they knew about their pain. Instead of believing that pain with movement meant damage, at follow-up many participants reported they now understood that pain with movement was in part due to tense back muscles. In addition to a new understanding of the relationship between their pain and the way they moved and postured themselves, many participants also reported the importance of understanding the multidimensional nature of their pain (that their thoughts and feelings could also influence their pain and behaviours).

The process of making sense of pain from a biopsychosocial perspective has been previously reported as an important aspect in the recovery of persistent pain (Bunzli, McEvoy, et al., 2016; Bunzli et al., 2017; Leake et al., 2021). With regards to the role of movement and posture in this process, it appears that the experiences of less or no pain with less protection during provocative tasks provided powerful learnings for participants that demonstrated that non-protective movement and postures were safe. This powerful experiential learning appeared to be an important element in disrupting the 'protect your damaged back' schema and promote the adoption of a new 'movement is safe' schema. In this way, rather than painful movements and postures being conceptualised as a threat, movement and posture (that was less protective) became therapeutic. While this process was reported by most of the participants, one participant demonstrated no meaningful shift in her pain or activity limitation and maintained threatening beliefs about movement, posture, and pain. The maintenance of similar negative beliefs about pain has been reported previously in a people that remained unchanged following CFT (Bunzli, McEvoy, et al., 2016).

7.3.2 Multidimensional schema disruption

Quantitative improvement to multidimensional factors, including pain experience (pain intensity, pain bothersomeness, and pain interference), activity limitation (RMDQ and PSFS), pain cognitions (such as LBP beliefs and pain self-efficacy), emotions (such as kinesiophobia), and movement or postural (T12 ROM and speed, lumbar EMG, and S2 position) suggests the presence of a multidimensional schema disruption (see 6.13.3). The heterogenous and individualised shift in these factors suggests that the way the schema is disrupted, and the key factors involved, varies between individuals. A similar pain schema disruption associated with concomitant changes in heterogenous factors such as pain intensity, pain controllability, and pain-related fear was reported in the Caneiro et al. (2019) SCED in four people undergoing a CFT intervention. The shift also aligns with the goals of CFT, which seeks to help people with disabling LBP reconceptualise pain from a biopsychosocial perspective while providing them with pain control strategies to develop confidence to engage in provocative, feared, or avoided valued functional tasks (O'Sullivan et al., 2018).

Most participants in the mixed methods study reported how important it was to have strategies (which were sometimes surprisingly simple) to control or reduce their pain during provocative movements and postures. This was supported by frequent improvements in pain control in the self-report questionnaires (see Section 6.13.3.2) and is congruent with the Caneiro et al. (2019) SCED that also observed important improvements in pain control. Similarly, the experience of improved pain control was a key finding among 'large improvers' from persistent LBP in a previous qualitative study investigating peoples experience of CFT (Bunzli, McEvoy, et al., 2016). Further, in a meta-ethnographic study of 195 qualitative studies exploring the journey of recovery from persistent pain, having helpful strategies to self-manage and live well was an important and common theme (Toye et al., 2021). Collectively, these findings suggest that having strategies to control pain during pain provocative and or feared functional movements and postures may be an important factor to disrupt the 'protect your damaged back' schema in individuals with disabling LBP.

7.3.3 Changing movement or posture as a vehicle to change the schema

Based on the reports of the participants in the mixed methods study at baseline, the powerful and aversive somatic experiences of pain with movements or postures played a key role in the negative psychological factors and protective behaviours of the ‘protect your damaged back’ schema. If pain is reduced (or eliminated) during previously painful movements or postures, then a large contributor to the schema is absent, potentially allowing space for an alternative narrative and the formation of a new schema. As discussed, tense, restricted, and stiff movements and postures in people with LBP were common at baseline in the mixed methods study, as they are in existing literature (Geisser et al., 2005; Laird et al., 2014; Laird et al., 2019; Pugh & Williams, 2014). Given these protective behaviours may in themselves be pro-nociceptive (O’Sullivan et al., 2018), modifying them to be less protective, more relaxed, and more normal may (in the right context and in the absence of specific pathology) provide a reduction in nociceptive activity and subsequent reductions in pain. Combined with personalised education that helps to make sense of this process, this pain reduction through changing movement and posture could be a potent catalyst to change negative pain-related cognitions and emotions, thereby disrupting the ‘protect your damaged back’ schema. Further, the active nature of this process may be particularly useful in improving self-efficacy and enhancing internal locus of control (Cross et al., 2006; Lackner & Carosella, 1999; Prompuk et al., 2018).

It is possible that other interventions that provide a narrative that makes sense and reduce pain with movement may result in a similar schema disruption through similar processes. For example, interventions such as spine stabilisation exercises (Richardson et al., 1999), movement pattern modification based on directional tendencies (Machado et al., 2006; McKenzie & May, 2003; Sahrmann et al., 2017; Van Dillen et al., 2013), or general exercise, have demonstrated some efficacy in improving pain and activity limitation in people with LBP (May & Johnson, 2008; Searle et al., 2015; Smith et al., 2014). Despite only modest effect sizes (Keller et al., 2007), it may be that these disparate interventions (with sometimes opposing advice that may even include advice to ‘protect’ (Dettori et al., 1995; Elnaggar, 1988)) share a similar mechanism in that they provide a narrative that makes sense and result in an experience of less pain with previously provocative movement. This, in turn, may de-threaten the LBP experience and catalyse a schema disruption that includes reduced pain or activity limitation and more positive psychological factors. An example of this process is demonstrated by the reductions in pain-related fear, more positive psychological factors, and improvements in pain and activity limitation in a person with persistent LBP receiving stem cell injection therapy, an intervention clearly not targeted at modifying movement or psychological factors (Bunzli, 2015). The mechanism of pain relief from the stem-cell injection may have been local regeneration of pain sensitive structures (Meiliana et al., 2018; Oehme et al., 2015), perceived safety or reduced threat related to no longer having a damaged structure (Brodal, 2017), placebo (Frisaldi et al., 2015), changes in other unmeasured factors, or a combination of the above factors. In this stem cell example, pain relief during movements and postures, and an alternative narrative (for example no longer believing that you have to 'protect your damaged back') may facilitate the schema disruption. It is possible that the process of having a narrative that makes sense and a method for pain relief also occurred in the instances where changes in movement showed relationships to changes in pain or activity limitation in both systematic reviews presented in Chapters 3 and 4, and in previous literature (Mannion et al., 2001; Steiger et al., 2012).

Pain relief alone, however, may not be sufficient to change movement, cognitions, and emotions that together disrupt the schema. There is evidence that movement patterns remain unchanged even after sufficient pain relief occurs (Williams et al., 2013; Williams et al., 2014). Similarly, even following LBP recovery, protective movement patterns can remain (Hodges et al., 2009; MacDonald et al., 2009), with negative psychological factors potentially playing a role in the persistence of those protective patterns (Thomas & France, 2007; Thomas et al., 2008). Further, modifying movement or posture alone may be insufficient in disrupting the schema given the only modest effect sizes for exercise interventions that target movement in a unidimensional way (Keller et al., 2007; Riley et al., 2019; Van Dillen et al., 2016). So, it may be that the *combination* of having an understanding that makes sense, enhanced pain control during previously provocative and individualised movements or postures, *and* no longer having beliefs that the back needs to be protected that is particularly salient in achieving the substantial improvements in pain and activity limitation observed in the studies in this thesis. This is consistent with studies exploring mediators of recovery from LBP (H. Lee et al., 2017), however there have been no studies exploring whether changes in movement or posture mediate LBP recovery. While speculative, gaining pain control during previously provocative movements through de-threatening active processes (such as during the behavioural experiments central to CFT) may contribute to the large and enduring effect sizes seen in CFT (Vibe Fersum et al., 2013; Vibe Fersum et al., 2019), a process mediated by enhanced pain-self efficacy (Costa Lda et al., 2011; Mansell et al., 2013; O'Neill et al., 2020). This may be the case even if movement or posture doesn't objectively change. Indeed, objective changes in movement or posture weren't always observed nor required to experience a schema disruption among participants in the mixed methods study. This suggests that the *perception* of change in movement or posture may be more important than actual measurable changes.

7.3.3.1 The perception of movement or posture being less protective may be more important than objective changes

In 20% (16 out of 82) of the relationships investigated in the single-case series presented in Chapter 5, pain or activity limitation improved despite not being related to objective changes in movement or posture. As discussed in Section 7.1.1 above, this may have been because those particular movement parameters were simply unrelated to that participant's pain or because broader unmeasured biopsychosocial factors were more related. Similarly, it may be because that participant moved 'normally' and didn't have a movement or postural 'impairment' in the first place, something that has been previously observed in a subgroup of people with LBP (Laird et al., 2018). Alternatively, it may also have been that the intervention was not successful at creating change, or the measurement tool was not sensitive enough to detect change. Nevertheless, in cases where relationships were not identified quantitatively, nor were objective kinematic or EMG changes in movement or posture observed, qualitative findings still suggested the importance of less-protective patterns in the participants narratives in Chapter 6 of this thesis.

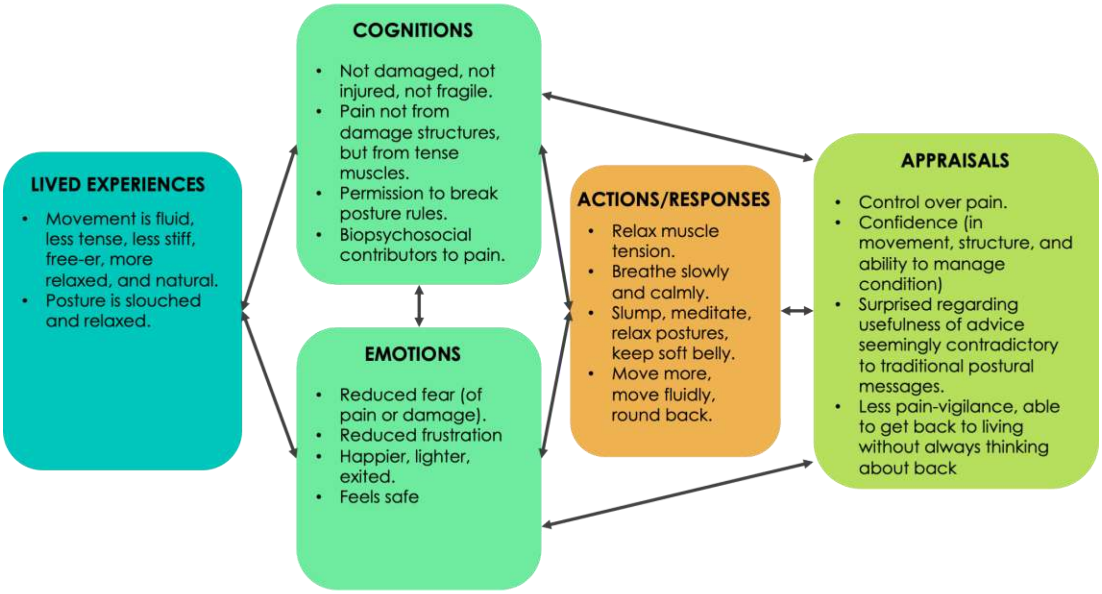
Participant 10 reported that standing in a "*more relaxed, not always as tense and anxious*" way and "*learning to relax her back*" were important in her recovery (see 6.13.4). This was despite objective measures of changes in her standing posture being unrelated to changes in her pain or activity limitation (see 5.8.3), as well as no apparent change to her pelvic tilt during standing from baseline to follow-up (see 6.13.3.2). It may be that the surface-based devices used to measure posture lacked sensitivity, especially to reliably identify small changes in posture. Similarly, other parameters that were not captured (such as static EMG during standing, which was a limitation of the device used) may have shown changes and therefore been related to improved pain or activity limitation. Nevertheless, despite qualitative changes towards more relaxed, less protective posture being reported as important in participant 10's improvement, objective measures did not support this. This suggests that perhaps the *perception* of change in movement or posture may be a more important part of the pain schema disruption than objectively measured changes and this might a helpful topic for further research. Similarly, Mannion et al. (2001) suggested that the positive experience of completing exercises without undue harm may have been the key ingredient in positive shifts in psychological factors and LBP improvement, rather than specific biomechanical changes.

Literature suggesting perceived back stiffness is different to objective back stiffness (Stanton et al., 2017) supports the lack of association between subjective and objective measures of biomechanical attributes. Similarly, there is some evidence that the mere subjective embodiment of a strong fit back can improve pain, cognitions, and perceived strength and confidence (Nishigami et al., 2019), showing that subjective, perceptual parameters can change without concomitant changes in objective parameters. Further, visualising the back with a mirror during movement has been shown to reduce movement-related pain in 25 people with LBP (Wand et al., 2012), suggesting that the perception of movement can influence the experience of pain. Indeed, many participants demonstrated positive shifts in their body perceptions as reported by the FreBAQ (see 6.13.3.2), supporting the potential role of perceptions (among other heterogenous factors) in the process of change.

7.3.4 Understanding recovery through the lens of the Common Sense Model

Changes to numerous cognitive, emotional, and behavioural factors accompanied the proposed schema shift from ‘protect your damaged back’ to ‘it’s safe to move’. **Error! Reference source not found.** presents this through the lens of the CSM.

Figure 7-2 Movement and posture forming part of a new embodied 'it's safe to move' schema through the lens of the Common Sense Model.



Through the lens of the CSM (Leventhal et al., 1980), participants' perceptions of their LBP is less-threatening compared to the previous 'protect your damaged back' schema (Figure 7-1). In addition to the potential mechanisms discussed below in Section 7.3.8, a less threatening narrative may itself contribute to less pain, given the link between pain and threat (Brodal, 2017; Moseley & Arntz, 2007).

In Chapter 6, many participants reported how their new understanding resembled a return to normal. They reported that they were able to get back to living without always thinking about their back – a state they were familiar with from before the onset of their back pain. This concept of becoming 'normal' again was also a recurring theme among 'large improvers' in a previous study investigating the experience of CFT in people with persistent LBP (Bunzli, McEvoy, et al., 2016). The reports of a return to a previous state of 'normal' suggests the presence of journey; from normal, to pain afflicted, back to 'normal'.

7.3.5 Carefree movement circuit

Many participants reported a journey from fluid, carefree, and nonconscious movements and postures before the onset of LBP at baseline; protective and careful movements while experiencing LBP; and a return to normal, non-protective, automatic, and fearless movements and postures at follow-up (Chapter 6). This journey suggests the presence of a 'carefree movement circuit'. Protective movement patterns observed in people with LBP compared to those without LBP (Geisser et al., 2005; Laird et al., 2014; Nolan, O'Sullivan, et al., 2019), and the frequent return to less protective movements and postures as LBP improved in Chapters 3, 4, and 5 of this thesis, provide further support for the potential presence of a carefree movement circuit in many people with LBP.

At follow-up in the mixed methods study, themes of automatic, normal, and non-protective movements or postures were common among the nonconscious non-protective participants that typically observed large shifts in pain, activity limitation, and psychological factors. Many reported no longer always thinking about their backs. Similarly, a 'forgotten joint' has been reported as the ultimate goal following joint arthroplasty, a position based on the premise that a normal healthy joint demands no awareness (Behrend et al., 2012). Together, these findings suggest a worthwhile aim for the movement or postures of people with persistent, disabling non-specific LBP may be to progress towards normal, carefree, and less protective patterns. Further, an emphasis on 'forgetting about back movement, posture, structure, and pain' may be a suitable 'end goal', but this requires further research. The process to get to that 'end goal', however, may be varied, difficult, and, for some, unsuccessful.

7.3.6 Targeting movement or posture is no panacea

Movement or postural based approaches are unlikely to help all people with LBP and don't show greater efficacy compared to therapeutic exercise or guideline-based care (Riley et al., 2019). Indeed, CFT (which is an integrated approach that targets unhelpful pain related cognitions, emotions, and behaviours) was unable to substantially help participant one in Chapter 6. Despite reporting glimpses where less-protective, more relaxed movements and postures were helpful (see 6.5.3.1), and some changes to her quantitative measures (see 6.4.2 or 6.13.3.3), participant one experienced no meaningful improvement. No shift was reported qualitatively or observed quantitatively, with changes in her activity limitation not exceeding clinically meaningful differences (M. K. Lee et al., 2017). There were also no strong relationships between changes in her movement and her pain or activity limitation (see 5.4). While no strong relationships does not necessarily mean no improved pain or activity limitation (P10 also demonstrated no strong relationships, yet still experienced a shift in her condition), there were several factors, such as persisting emotional distress and damage beliefs, that potentially contributed to P1's lack of improvement (discussed in 6.5.3.1).

The finding that changes in movement aren't consistently related to changes in pain or activity limitation in the studies presented in this thesis, as well as the identification of a subgroup of people with LBP who move 'normally' (Laird et al., 2018), highlights that modifying movement or posture to be 'less protective' should not be a target for all people with non-specific LBP. Indeed, interventions such as stabilisation exercises that encourage *more protective* spinal movement have demonstrated an ability to improve LBP (Mannion et al., 2001; May & Johnson, 2008; Smith et al., 2014). However, effect sizes are modest and changes in measures of stability do not appear to account for the observed changes in activity limitation (Keller et al., 2007; Mannion et al., 2012; Steiger et al., 2012). Interestingly, improved spinal ROM (as measured by finger-tip-to-floor – a surrogate measure for spinal ROM) and pain catastrophising *did* contribute to explaining the variance in activity limitation in a study of stabilisation exercises (Mannion et al., 2012). This led to the authors suggesting that a more 'central effect' was responsible for the improved activity limitation rather than changes in spinal stability (Mannion et al., 2012). That increased ROM and reduced pain catastrophising explained the variance in activity limitation change in the Mannion et al. (2012) study further supports our findings of less protective movement related to improved LBP in this thesis. In summary, there are likely many ways to positively influence a 'central effect' and improve LBP, and modifying movement or posture appears to be one of these ways.

7.3.7 Association does not imply causation

While movement and posture often (but not always) returned towards being less protective when related to LBP improvement in the studies presented in this thesis, the findings are of association only. We observed changes to multiple movement, posture, pain, activity limitation, cognitive, and emotional factors, however, the directional relationship and underlying mechanisms (what drives what) remain unknown.

The finding that most (54%) of the strongest cross-correlation relationships occurred at a time-lag of zero weeks (Chapter 5) suggests that most commonly, changes between movement and pain or activity limitation occurred concomitantly. That the strongest relationship occurred 31% of the time at a positive lag (when movement data changed earlier than pain or activity limitation data), provides some indication that for some people changes in movement *preceded* changes in pain or activity limitation. Finally, the strongest relationship occurred 15% of the time at a negative lag (when movement data changed *later* than pain or activity limitation data) (see 'time-lag results' in Section 5.4). Taken together, these results suggest that temporal relationships are variable but more commonly occur concomitantly.

Similar findings of concomitant changes were found in the Caneiro et al. (2019) SCED. In that study, changes in pain, pain controllability, and fear were most strongly associated with changes in activity limitation at a time-lag of zero (Caneiro et al., 2019). The findings of both the single-case series by Caneiro et al. (2019) and the single-case series presented in Chapter 5 support a frequent occurrence of a concomitant schema shift of movement, posture, pain-related cognitions and emotions, pain, and activity limitation. Notably, assessment frequency occurred approximately weekly in both studies, and it is unknown whether more frequent and granular measures (for example daily, or within-session) would provide the same results. While there have been advances in causal modelling concepts since the Bradford-Hill criteria (Fedak et al., 2015), one of the nine viewpoints to help determine if associations are causal in those criteria is about temporality (Hill, 1965). If future studies at more granular timepoints suggest changes in movement consistently precede changes in pain or activity limitation, then this may provide some indication that changes in movement potentially *caused* changes in pain or activity limitation, especially if the strength of association is strong and occurs under experimental control, such as in a single-case experimental design (Hill, 1965; Tate, Perdices, Rosenkoetter, McDonald, et al., 2016). Mediation studies with larger samples would provide additional useful insights into causal relationships (Kent et al., 2019; Lee et al., 2019).

7.3.8 Potential mechanisms of change

The concomitant and heterogenous shift in several multidimensional factors observed in many of the people with LBP in this thesis supports the concept of a multidimensional pain schema shift proposed by Caneiro et al. (2019). It is speculated that the surprising experiences of less (or no) pain while performing previously provocative movements and postures in a more relaxed, less protective way acts as a strong vehicle to trigger the multidimensional re-conceptualisation of a person's understanding of their LBP. Specifically, when accompanied by a less-threatening narrative that makes sense through personalised education, the 'protect your damaged back' schema is 'dis-embodied' and the new 'it's safe to move' schema is embodied. Therefore, the re-conceptualisation of LBP appears to be an experiential learning process secondary to the behavioural experiments and exposure (with pain control) to threatening tasks that make up a key part of the CFT intervention (O'Sullivan et al., 2018).

7.3.8.1 Inhibitory learning

In the context of exposure therapy, the expectation of pain may represent a conditioned response following several prior experiences of that movement (a conditional stimulus) being followed by pain (the unconditional stimulus) (Craske et al., 2014). In this way, an association is posited between the memory representation of the conditional stimulus (movement) and the unconditional stimulus (pain) such that presentations of the conditional stimulus will indirectly activate the memory of the unconditional stimulus (Craske et al., 2014). In addition to the activation of the pain memory, it seems a behavioural response of pro-nociceptive tense, guarded, and protective behaviour may also occur (O'Sullivan et al., 2018), further perpetuating the pain experience. From a neurobiological perspective, the terminology of 'memory representations' used in the exposure literature could represent a neural representation or cortical matrix that encompasses the neuro-immune-endocrine system (Brodal, 2017; Wallwork et al., 2016). While speculative, this neuro-immune-endocrine response may be associated with a 'protect your damaged back' schema.

The key mechanism behind improvement following exposure therapy is reported to be inhibitory learning (Craske et al., 2014; Weisman & Rodebaugh, 2018), although other mechanisms, such as habituation, are likely to be involved (Myers & Davis, 2007). While speculative, it is possible that new safety learnings prompted by the 'un-coupling' of the 'conditional stimulus (movement) – conditioned response (pain)' relationship during the behavioural experiments and the making sense of pain process inhibited the activation of the pain memory. This is supported by the reductions in fear and improved pain-related cognitions observed in the mixed methods study. Additionally, less nociceptive activity secondary to the less protective, more relaxed movements likely also contributed to reduced pain (O'Sullivan et al., 2018). In the context of neural mechanisms, this extinction or inhibitory learning process may involve the inhibition of the activated amygdala (a person's 'fear centre') (Shin & Liberzon, 2010) by cortical influences from the medial prefrontal cortex (the integrative hub for emotional, sensory, social, memory, and self-related information processing including painful experiences (Roy et al., 2012)) (Milad et al., 2009; Milad et al., 2007). In this way, it appears that an inhibitory learning process, where experiences of safety with movement or postures inhibit previously painful associations, may form part of the key mechanisms underpinning improvement (Craske et al., 2008; Craske et al., 2014). This inhibitory learning mechanism is postulated to have occurred when improved pain or activity limitation was related to less protective movement (included *perceived* less protective movement) but may also occur during generic instances of less pain with movement or posture (i.e., during movements or postures that are *not* specifically 'less protective'), or with other interventions. Experiences of safety that are repeated in various contexts may enhance this inhibitory learning mechanism, promoting positive shifts pain control, self-efficacy, and other psychological factors (Asghari & Nicholas, 2001; Craske et al., 2014). Indeed, many participants in Chapter 6 reported the integration of less protective movement into valued tasks as important.

7.3.8.2 Positive shifts in psychological factors

Large shifts in various psychological factors were also observed in the participants of the mixed methods study. Psychological factors have been previously reported as important mediators for LBP improvement (Lee et al., 2019; Lee et al., 2015; Mansell et al., 2016), and often show stronger associations to changed clinical outcome than changes in movement or posture (Mannion et al., 2001; Mannion et al., 2010; Mitchell et al., 2010; Nordstoga et al., 2019). It is likely that the inhibitory learning process secondary to education and less pain when movement or posture was modified, also involved positive shifts in important psychological factors. A recent study suggesting that changes in self-efficacy account for the greater reductions in pain-related disability seen in individualised CFT compared to contemporary group education and exercise provides support for the important role of individualised psychological factors as mechanisms underpinning LBP improvement (O'Neill et al., 2020). However, no measures of movement or posture occurred in the O'Neill et al. (2020) study, limiting the ability to make inferences about whether changes in movement or posture accounted for any change in outcome. Self-efficacy (as well as pain catastrophising) was also different between the conscious non-protection and the nonconscious non-protection groups in the mixed methods study in this thesis. Previous research has implicated self-efficacy and pain catastrophising as important LBP treatment mediators (Mansell et al., 2013), providing further support for our findings and the important role of positive shifts in psychological factors when considering the mechanisms that may underpin LBP improvement.

7.4 Similarities to existing literature

As discussed above, the qualitative and quantitative findings of this thesis were generally well supported by previous literature. Qualitative reports of stiff, tight, restricted, and frightening movements or postures that return to more normal, fluid, and relaxed patterns following recovery have been reported previously (Bunzli, Smith, Watkins, et al., 2015; Hush et al., 2009; Pugh & Williams, 2014). Similarly, quantitative findings of protective movement patterns are well documented in the literature (Geisser et al., 2005; Laird et al., 2014; Laird et al., 2019). Additionally, there are distinct similarities between some of the concepts identified in the findings of this thesis and previous literature, both from within the health field and more broadly.

7.4.1 Gadow's states of embodiment

In her 1980 paper, Sally Gadow elaborated on the perspective outlined by the French phenomenologist Merleau-Ponty that all human perception is embodied (Gadow, 1980; Merleau-Ponty, 1945). Gadow described a dynamic dialectical relationship between body and self, in which illness or disease can be conceptualised as a breakdown or disruption of body-self unity (Gadow, 1980).

According to Gadow, four states between the 'body' and 'self' characterise human embodiment.

1. The first state is 'Primary Immediacy – the Lived Body'. In this state a person experiences no conscious distinction between their body and self. They take their body for granted and are not thinking it (Gadow, 1980; Hudak et al., 2007). In the context of this thesis, this may resemble people before they have LBP, when they aren't usually thinking about their back. Interestingly, findings discussed in section 7.2.3 identify that many people among society without LBP already hold strong negative beliefs about their back. This may suggest that a state of primary immediacy may not be present among some people, a speculation that likely depends on a person's social context and previous experiences (lived or vicarious). For example, they may have a family member with LBP that means they often think about their back, even if they don't experience LBP themselves.

2. The second state of embodiment reported by Gadow is 'Disrupted Immediacy – the Object Body'. In this state a person experiences disunity and tension between their body (or body part) and self. There is an acute or intense conscious awareness of the body part. In the context of this thesis, this may resemble the conscious experience of LBP and the perceived need to protect the back that is embodied through slow, restricted, and guarded movement or posture.

3. The third state of embodiment is ‘Cultivated Immediacy – Harmony of the Lived and Object Body’. In this state a person has recovered a sense of unity between the body and self. They learn to live with and become accustomed to the disrupted immediacy. Eventually, the disunity fades into the background of consciousness (Gadow, 1980; Hudak et al., 2007). The embodied return to nonconscious non-protective movement and posture (faster, greater ROM, and more relaxed) commonly observed in the findings of this thesis shares similarities to this state, as does the premise of the forgotten joint scale (Behrend et al., 2012).

4. The fourth state reported by Gadow was ‘Aesthetic Immediacy – the Subject Body’. In this state, a person (often upon reflection or following the initial acute experience of disunity) recognizes that their body or body part has its own meaning, values, and purpose (Gadow, 1980; Hudak et al., 2007). Despite the persistence of symptoms or indications of disease, the problem is viewed as positive. While most participants in the mixed methods study reported substantial improvements, there were glimpses where the participant who did not improve (P1) reported a reframing and recalibration of her condition and had a seemingly more positive outlook on her condition at follow-up (see Section 6.4.1.2.2).

Several other authors have reported on the conceptualisation of pain as an experience that is embodied (Bullington, 2009; Lape et al., 2019; Snelgrove et al., 2013; Stilwell & Harman, 2019; Tarr & Thomas, 2011) further supporting the embodied protective movement and postural patterns observed in this thesis. In addition to this and other models from the health field, similarities were also observed between the findings of the thesis and fields such as education.

7.4.2 Conscious competence model of learning

The progression from nonconscious and conscious protection, to conscious non-protection (four participants), and eventually nonconscious non-protection for many (seven participants) that was organically derived from the qualitative interviews in Chapter 6 shares distinct similarities to the conscious competence model of experiential learning (Cannon et al., 2010). The conscious competence model suggests four stages in the learning of complex skills: unconscious incompetence, conscious incompetence, conscious competence, and unconscious competence (Cannon et al., 2010). The similarities demonstrate some external verification from a field outside of healthcare about the content validity of our findings. However, no studies were identified that formally validate the conscious competence model.

7.4.3 Theory of behaviour change

The conscious non-protection and nonconscious non-protection stages reported in the mixed methods study in Chapter 6 also share similarities to the action and maintenance stages of the well-accepted 'transtheoretical model of behaviour change' (Prochaska & Velicer, 1997; Spencer et al., 2006). This validated model posits that health behaviour change involves progress through six stages of change: precontemplation, contemplation, preparation, action, maintenance, and termination (Prochaska & Velicer, 1997). It appears then that the protection to non-protection stages presented in the mixed-methods study in Chapter 6 may be useful in theoretical models for understanding behavioural changes in many people recovering from LBP, however that is a topic for further research.

7.5 Perspectives and potential implications

This thesis aimed to explore questions about the relationship between movement, posture, and LBP. Contrary to previous literature, we found that changes in movement and posture *frequently* related to changes in pain or activity limitation when heterogeneity was accommodated. The frequent relationship between changes in movement or posture and changes in pain or activity limitation, however, was not in the direction that traditional advice about posture and movement would suggest for people with LBP. 'Protective' advice to maintain 'good' posture, keep the back straight, and brace trunk muscles are common among interventions for people with persistent non-specific LBP (Darlow, 2016; Slater et al., 2019; Smith et al., 2014), as well as in efforts to prevent LBP (Martimo et al., 2008; Verbeek et al., 2011). While the findings from this thesis can't answer questions about LBP prevention, we almost always observed movement or posture becoming *less* protective (increased ROM, increased movement speed, increased relaxation, increased pelvic slouching) when related to LBP improvement. Movement or posture consistently changing in the opposite direction to the dominant 'protective' movement or postural advice raises questions about the validity of that advice, at least in persistent non-specific LBP.

There are consistent findings of objectively measured protective movements and postures among people with LBP both in this thesis, and in existing literature (Geisser et al., 2005; Laird et al., 2014; Nolan, O'Sullivan, et al., 2019). There are also consistent reports of careful, stiff, tense, fearful, guarded, and restricted movement and posture from qualitative studies in people with LBP both in this thesis and in existing literature (Bunzli, Smith, et al., 2016; Bunzli, Smith, Watkins, et al., 2015; Oosterhof et al., 2014; Pugh & Williams, 2014; Snelgrove et al., 2013). Additionally, we observed consistent findings of *less protective* objectively measured movement and posture when changes were related to improved LBP both in the empirical studies presented in this thesis and in the two systematic reviews of existing literature. We also identified qualitative reports of *less protective* and more normal carefree movement and posture before the onset of LBP among people with disabling LBP in this thesis and note the *less protective* movement patterns objectively measured among people without LBP in existing literature comparing people with and without LBP (Geisser et al., 2005; Laird et al., 2014; Nolan, O'Sullivan, et al., 2019). Collectively, those findings suggest that the focus on 'protect your back' demands further investigation, as preliminary evidence suggests it may not be protective and may in fact prolong symptoms and limit recovery.

The empirical studies of this thesis focussed on a small group of people (n = 12) with persistent, disabling non-specific LBP. It is therefore unknown whether the findings from this thesis are generalisable to the management of people with acute LBP, less disabling LBP, LBP due to specific pathology, or to larger LBP populations. Although, the consistently less protective movement when related to LBP improvement that was observed in the relationships of almost 3,000 people with LBP (both acute and persistent) in the systematic reviews does question the utility of the 'protect your back' narrative among larger LBP populations. Similar to inappropriate imaging resulting in iatrogenic harm through the potential nocebic communication of the imaging findings (Jacobs et al., 2020; Rajasekaran et al., 2021; Webster & Cifuentes, 2010) and in line with calls that disabling non-specific LBP may in part be iatrogenic (Lin et al., 2013; Loeser & Sullivan, 1995), could it be that implicit or explicit messages to 'protect your back' from well-meaning friends, family, or clinicians have unintended iatrogenic consequences in some vulnerable populations? Previous research reports that health messaging and the use of language can have potentially powerful influences on clinical outcomes (Friedman et al., 2021; Rajasekaran et al., 2021; Stewart & Loftus, 2018). While speculative, it could be that messages to 'protect the back' perpetuate an enduring threatening narrative that the spine is fragile and vulnerable. It may also inadvertently maintain a structural or biological focus despite the growing evidence that psychological factors are better predictors of pain and disability levels than pathoanatomical or biomechanical factors (Burton et al., 1995;

Chester et al., 2018; Ivarsson et al., 2013; Mannion et al., 2012; Mannion et al., 2001; Nordstoga et al., 2019; Pincus et al., 2002).

7.5.1 A change in the back pain narrative?

A lack of clear evidence that supports the 'protect your back' narrative among persistent non-specific LBP populations and the consistent evidence of less protective movement and posture when related to LBP improvement observed in this thesis suggests it may be time to rethink the traditional 'protect your back' narratives in people with persistent non-specific LBP. In line with current evidence supporting the heterogenous aetiology of LBP (Foster et al., 2018; Maher et al., 2017) and, calls for change in the management of LBP (Buchbinder et al., 2020; Buchbinder et al., 2018; O'Sullivan, 2012; Tousignant-Laflamme et al., 2017), the findings from this thesis suggest there may be scope for an alternative narrative. A possible alternative narrative that encompasses movement and posture and aligns with contemporary literature may be: '*Low back pain is complex and influenced by many multidimensional factors. Pain with movements or postures doesn't necessarily mean you're doing harm and it's safe to relax during everyday movements and postures (O'Sullivan et al., 2019).* This alternative narrative, however, requires further research to explore its acceptability and effectiveness, including input from people with a lived experience (Belton et al., 2019).

In support of the suggested alternative narrative, key themes that were valued by people who had recovered from persistent pain were related to understanding that pain does not mean damage, pain is multidimensional, and pain can be lessened (Leake et al., 2021). Similarly, the re-conceptualisation of pain from a biopsychosocial perspective, having skills to achieve independence, the validation of pain and the person with pain, reconnection to valued personal activities and society, being kind to oneself, and having hope for the future were important concepts in the recovery from persistent pain (Bunzli, McEvoy, et al., 2016; Toye et al., 2021). Additionally, there is some evidence suggesting that using and loading the spine is beneficial for spinal structures (Battié et al., 2009; Belavy et al., 2018; Belavy et al., 2017; Mitchell et al., 2020; Owen, Hangai, et al., 2020), further questioning whether avoiding activities (based on the belief that this will protect the back and preserve spinal structures) is warranted among people with persistent, non-specific LBP (Vlaeyen et al., 2016; Vlaeyen et al., 1995; Vlaeyen & Linton, 2006). In contrast, subjectively reported heavy physical workloads have been shown to relate to LBP (McDermott et al., 2012) and a six-month spinal exercise and loading program did not show beneficial adaptations of the intervertebral disc (Owen, Miller, et al., 2020). This may reflect the potential applicability of the ‘goldilocks principle’, where too little or too much movement or loading is unhelpful, but just the right amount (in the right biopsychosocial context and with the right recovery) is healthy (Heneweer et al., 2009; Lotz, 2011; Straker et al., 2018).

Given unhelpful beliefs about LBP relate to more pain, activity limitation, work absenteeism, medication use, and healthcare seeking (Main et al., 2010), the provision of alternative narratives that align with contemporary evidence may help ensure that unhelpful beliefs about LBP negatively impact the recovery of fewer people. Many unhelpful beliefs about LBP relate to movement and posture (O’Sullivan et al., 2019; Slater et al., 2019), highlighting the potential need for accurate healthcare messaging in this space. Despite some evidence that community education can positively influence beliefs (Buchbinder & Jolley, 2004; Buchbinder et al., 2001; Gross et al., 2010), there is currently limited evidence that persistent pain trajectories can be positively modified (Chen et al., 2018; Delitto et al., 2021; Morsø et al., 2021), highlighting the significant challenge ahead. The sometimes long, challenging, and occasionally unsuccessful journeys of participants in the empirical studies of this thesis attest to the challenge of effectively managing people with LBP.

7.6 Strengths and limitations of thesis

The strengths of the systematic reviews presented in Chapters 3 and 4 of this thesis include their prospective registration, the use of independent reviewers, and the use of PRISMA reporting guidelines. Further, GRADE assessments, the assistance of a senior faculty librarian in developing the search strategy, and the inclusion of single-case literature that is commonly omitted from systematic reviews, were additional strengths. Limitations include a potential language bias given that we only included studies published in the English language, potential publication bias, and the potential for selective reporting in the primary literature. Additionally, the exclusion of pharmacological and surgical interventions, the arbitrary $p<0.05$ threshold when identifying a significant statistical relationship, vote counting (although heterogeneity prevented meta-analyses), and the overall low quality determined by the GRADE assessment criteria are further limitations.

For the single-case series presented in Chapter 5, strengths include that it was prospectively registered and repeated (up to 20) measures of person-specific movements and postures were collected by an assessor blind to pain and activity limitation data. We used a multidimensional, individualised intervention that has demonstrated large effect sizes in similar populations in an attempt to create change (Vibe Fersum et al., 2013). The cross-correlation of relationships between objectively measured and self-reported data, and the replication of the relationship across many participants with findings aligning to previous systematic reviews that strengthens generality (Tate et al., 2013), are further strengths. Finally, the study was reported in accordance with the SCRIBE guidelines (Tate, Perdices, Rosenkoetter, Shadish, et al., 2016).

Also of note is that we used a single-case design due to the ability for these designs to accommodate person-specific measurements and allow investigations into individualised relationships (Tate, Perdices, Rosenkoetter, McDonald, et al., 2016). While single-case designs *can* be used to investigate treatment effects (for example by using experimental designs, randomised baselines, and other methodological approaches (Tate, Perdices, Rosenkoetter, McDonald, et al., 2016)), this was not our aim. We were *not* interested in exploring the efficacy of Cognitive Functional Therapy as part of this thesis. Rather, we used CFT as a method to attempt to create change in movement, posture, pain, or activity limitation which subsequently allowed the investigation of relationships between these factors.

Limitations of the single-case series include the small sample (n = 12). Therefore, clinicians are encouraged to compare the characteristics of their clinical population with those of the sample in the single-case series when considering generalisability. Notably, generalisability is not simply a matter of sample size or study design (Kazdin, 2021) and many factors such as non-random sample selection or stringent inclusion and exclusion criteria's influence generalisability (Guthrie, 2004; Kazdin, 2021).

While the repeated measures in the single case series represent a strength, they may have also resulted in task familiarisation (although visual inspection often identified stable baselines). Further, the use of an intervention that often explicitly targets movement or posture meant we may have observed a relationship more commonly than if other interventions were used. There was also significant researcher-participant contact due to the repeated measures and qualitative interviews which may have enhanced the treatment effect or enhanced a social desirability bias (Latkin et al., 2017). The evidence is also only of association and the potential influence of recall bias should be considered (McPhail & Haines, 2010). Further, we were limited to T12 and S2 movement sensors which are unable to directly measure intra-lumbar kinematics. We also only output data in the sagittal plane from global trunk or pelvis angles. Similarly, heavy EMG filtering by the manufacturer's software meant we were unable to measure very low levels of EMG (for example during static postures).

Reduced ability of the wearable sensors to identify smaller changes in kinematics or static EMG may have influenced the different frequency of relationships identified among movement compared to postural parameters in Chapter 5. Relationships between changes in movement and changes in pain or activity limitation were identified 80% (53 out of 66) of the time, while they were only identified 50% (8 out of 16) of the time when relationships were investigated among postures. This may be because changes in kinematics and EMG during activities, such as bending and lifting, may be significantly larger than changes observed during static postures, making change relationships less likely during postures (as the possible amplitude of kinematic change is reduced). Additionally, there were fewer relationships investigated during postures (16 investigations for posture compared to 66 for movement), meaning relationships with postures may have been less common simply because they were investigated less frequently. Despite the limitations of these wearable sensors to measure minute changes in movement or posture, these devices still demonstrate good to excellent validity and inter-rater reliability in the lumbar spine (Mieritz et al., 2014; Mjosund et al., 2017; Poitras et al., 2019). For example, differences of between one and three degrees in the sagittal plane compared to the VICON motion capture system, the industry standard, support their validity (Mjosund et al., 2017).

For the mixed methods study presented in Chapter 6, strengths include that it was also prospectively registered, the COREQ checklist was followed, as were several mixed methods appraisal tools. Furthermore, longitudinal qualitative and quantitative measures and the integration of these approaches provided a more comprehensive understanding than either of these approaches alone (Fetters & Freshwater, 2015). Additionally, the frequent use of multiple (usually five) measurement timepoints within both the baseline and follow-up phases reduces the likelihood of chance fluctuations or outliers influencing measures (of movement, posture, and self-reported outcomes). Limitations include the small sample, the possibility for response bias (such as the participants trying to please the researchers), the low representation (one participant) of participants who didn't change, and the inability to make causal inferences given the associative nature of the design. Further, the inductively generated themes about conscious and nonconscious protection and non-protection may have limited transferability until the findings are replicated. Additionally, as the intervention frequently targeted changes in movement, posture, pain, psychological factors, and activity limitation, it is unknown if similar findings would have been observed with other interventions, although less protective movement when related to LBP improvement identified in the systematic reviews suggests this finding may have some generalisability.

7.7 Future research directions

Two key areas emerge as opportunities for future research; a) understanding the complex, multidimensional relationships contributing to disabling LBP and its recovery (including the role of movement and posture in causal pathways), and b) investigating the utility and generalisability of ‘less protective’ patterns, including whether societal, public health, and clinical messages that ‘de-threaten’ movement and posture can help reduce the likelihood or impact of disabling LBP. The rationale and recommendations that may achieve those objectives are described below.

Current understanding about the causes of LBP does not clearly point to one specific cause but posits that it is a multidimensional and individual process (Hartvigsen et al., 2018). With the advancement of wearable technology, the evolution of research designs (Bentley et al., 2018; H. Lee et al., 2017), and the emergence of ‘big data’, machine learning, and artificial intelligence (Adibuzzaman et al., 2018), future studies are likely to have the capacity to analyse large volumes of multidimensional data. This may facilitate the provision of robust estimates on what the dominant factors are that lead to the development of disabling LBP and what factors mediate LBP improvement. Multidimensional data might include variables such as physiological data including kinematic, kinetic, EMG, cortisol, inflammatory, sleep, heart rate variability, breathing patterns, or physical activity; frequent self-report outcomes of pain, activity limitation, and psychological data (for example through ecological momentary assessment on smartphone devices (Shiffman et al., 2008)); healthcare utilisation, socio-demographic, and social determinants of health data; as well as other potentially important factors. This would provide insights into targets for the management of LBP and may assist in efforts to prevent disabling LBP, a notoriously difficult task (Delitto et al., 2021). Whether targeting these important factors is most efficacious and cost-effective at primary prevention (avoiding all LBP and potentially harmful activities), secondary prevention (reducing the impact of pain when pain is unavoidable), or tertiary prevention (reducing ongoing activity limitation or distress due to persistent, disabling pain) levels may provide additional important insights (Fisher & Eccleston, 2021; Foster et al., 2018).

A tangible first step may be studies investigating relationships between multidimensional factors using repeated measures at more granular timepoints (such as within session). Similarly, investigating which psychological, pain, or activity limitation factors demonstrate the strongest relationship with changes in movement or posture over time may also provide important insights into movement and posture. Further, there are currently studies underway that are designed to investigate questions about whether changes in movement mediate changes in activity limitation (Kent et al., 2019). Similarly, high quality studies with larger sample sizes, that adopt a complex systems approach, frequently measure multidimensional factors, utilise mediation analyses, and exercise experimental control would provide further useful insights into important relationships between movement, posture, pain, activity limitation, and other multidimensional factors.

Less protective movement (and posture) when related to LBP improvement was a consistent finding amongst this body of work. However, relationships were not consistently identified (especially in the systematic review of cohort and RCTs). While many factors may influence the presence of a relationship as discussed in Section 7.1.1, larger studies investigating whether movement and posture changes towards less protective patterns as LBP improves at the individual level using a variety of interventions would provide further information about the generalisability of this finding. Such research may provide useful insights into the utility of the protection to non-protection journey identified in the mixed methods study. Additionally, whether alternative health messages that ‘de-threaten’ movement or posture are useful in reducing activity limitation or preventing disabling LBP requires further research. The optimal way to deliver messages about movement and posture (that include important concepts such as the multidimensionality of LBP) to ensure they are well-accepted also requires further research, ideally in collaboration with people with a lived experience (Belton et al., 2019). Potential methods may be through mass media campaigns or clinician facing training (Buchbinder et al., 2001; Gross et al., 2010; Suman et al., 2020; Whiteley et al., 2020).

7.8 Conclusions of thesis

The body of work presented in this doctoral thesis has aimed to investigate important and surprising gaps in our understanding of the relationship between movement, posture, and LBP in a rigorous, and clinically informative way. We did this using existing longitudinal literature involving almost 3,000 people with LBP from many parts of the world, as well as in-depth and frequent quantitative measures of numerous multidimensional factors in 12 people with persistent, disabling non-specific LBP. Kinematic and EMG parameters were repeatedly measured using validated wearable sensors and by an assessor blind to clinical outcome data. We also used well-accepted self-report questionnaires. Additionally, longitudinal qualitative methods gave voice to the stories and experiences of those 12 people, with their conceptualisations integrated with individualised quantitative measures.

The systematic reviews in Chapters 3 and 4 identified that relationships between changes in movement occur at differing frequencies depending on the literature sampled. Among cohort studies and RCTs, relationships were infrequent, but limitations surrounding the inability to readily accommodate heterogeneity and the low overall quality of the evidence limited our confidence in the findings. When systematically reviewing single-case studies, a design that *is* more readily able to accommodate heterogeneity, relationships were far more frequent; however, the quality of evidence was still low. Both systematic reviews consistently identified less protective movement when related to LBP improvement, suggesting a return towards normal movement that resembles that of people without LBP.

Addressing limitations highlighted by the two systematic reviews, the replicated single-case design presented in Chapter 5 aimed to understand individualised relationships using repeated (up to 20 over 22 weeks) measures of movement, posture, pain, and activity limitation in 12 people with persistent, disabling non-specific LBP. These factors were measured before, during, and after a CFT intervention. The findings highlight that, contrary to existing cohort literature, changes in *individualised* movement and posture *frequently* related to changes in pain or activity limitation. Again, in the presence of a relationship, less protective movement or posture was consistently related to improved pain or activity limitation, a finding almost identical to the systematic reviews. The person-specific movements or postures and most related movement or postural parameters varied considerably among the participants, supporting the presence of movement and postural heterogeneity as well as calls for individualised approaches.

In the final study of this thesis, a mixed methods investigation presented in Chapter 6, qualitative and quantitative findings from the baseline and follow-up periods of the single-case design presented in Chapter 5 aimed to conceptualise links between movement, posture, and LBP in those 12 people. The findings highlighted a re-conceptualisation of movement and posture, from a threatening activity to a therapeutic recovery strategy. A journey from embodied nonconscious and conscious protection to conscious non-protection, and eventually (for many) nonconscious non-protection and just living was identified. This journey was characterised by person-specific quantitative changes in movement, posture, and psychological factors that broadly supported the qualitative findings. During the integration of qualitative and quantitative findings, quantitative changes in pain self-efficacy and pain catastrophising distinguished between people still in conscious non-protection and those that progressed to nonconscious non-protection based on qualitative interviews at follow-up, supporting the potential importance of these psychological factors in the recovery journey.

Taken together, the findings of this thesis support the multidimensional interplay between numerous biopsychosocial factors (including movement and posture) in the manifestation of a ‘protect your damaged back’ schema in people with LBP. Protective movement and posture that is slow, restricted, and tense appear to represent an embodiment of this schema and a common-sense response to the pain-related cognitions, emotions, and experiences reported by people with LBP. While speculative, this schema may in fact be unhelpful, perpetuating LBP through cortical matrixes and neuronal networks that represent threat, as well as through pro-nociceptive muscle guarding. In conjunction with positive shifts in pain-related cognitions and emotions, the re-conceptualisation of non-protective movement and posture as therapeutic highlights that an alternative less threatening narrative and the embodiment of a new schema (such as ‘it’s safe to move’) may be an important part of LBP improvement for some people. Experiential learning through behavioural experiments that disconfirmed negative LBP beliefs appeared to be important at disrupting the ‘protect your damaged back’ schema.

The findings of this thesis lend support to the deeply held belief that movement and posture play an important role for many with LBP, but not in the way we have traditionally believed. Contrary to common advice to ‘protect your back’, ‘have proper posture’, and ‘be careful with your movement’, we consistently observed a return towards *less protective* movement or posture when related to LBP improvement. However, this finding was an association only and does not indicate that less protective movement *caused* changes in LBP. Further, high quality research using larger samples is required to establish generalisability. While many of the participants in the empirical studies of this thesis demonstrated a positive shift, the journeys were individualised and variable, with one participant not demonstrating a shift. A frequent but not consistent relationship further suggests that for some people with LBP, movement or posture may not play an important role.

Much remains unknown about the relationship between changes in movement, posture, and LBP. Future studies with larger samples that include mediation analyses, involve experimental controls, utilise a complex systems model, and collect frequent measures of individualised multidimensional factors would prove useful to help unravel the complex relationships that exist between movement, posture, psychological factors, and LBP.

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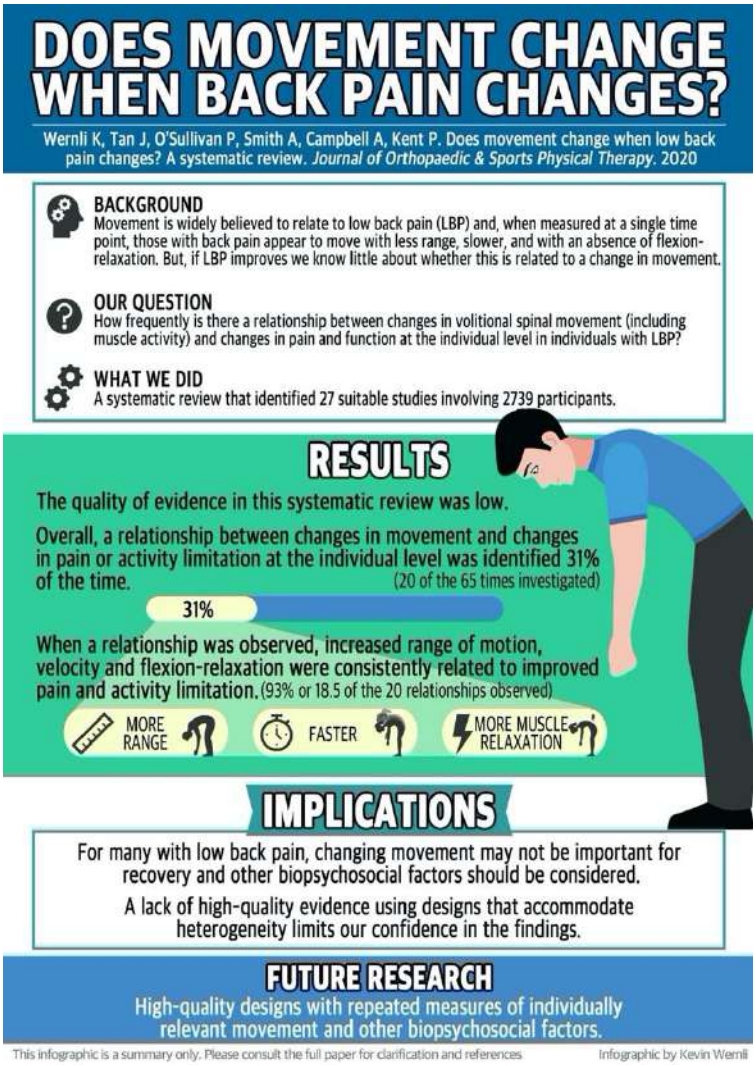
Chapter 8 Thesis Appendices

Appendix A Research translation materials

A.1 Infographics and video abstracts produced for Chapters of this thesis

A.1.1 Chapter 3: Systematic review: Cohort studies and RCTs

Figure 8-1 Infographic. Systematic review: Cohort studies studies and RCTs

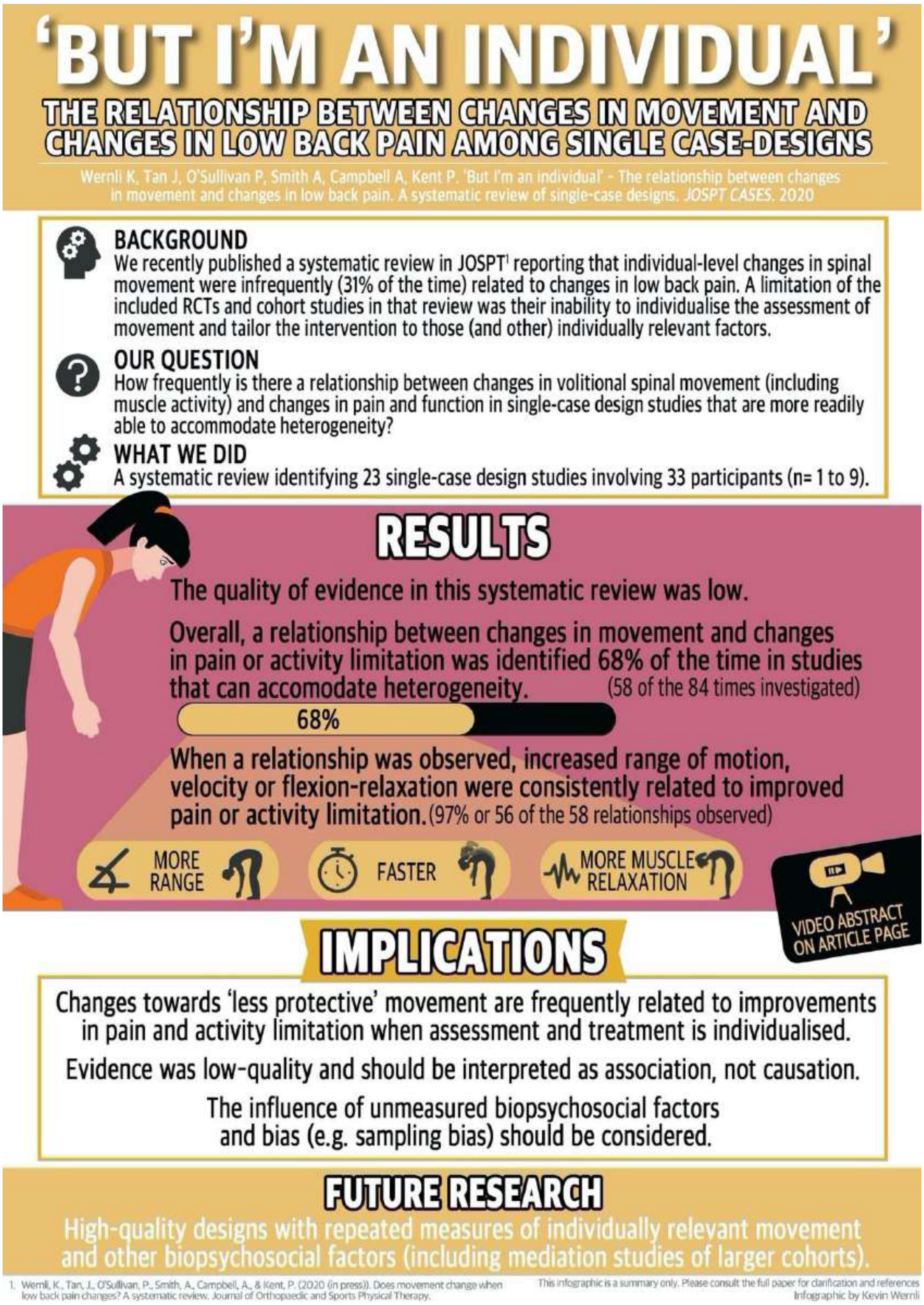


Full video abstract: https://youtu.be/iUgVOdtQPi8

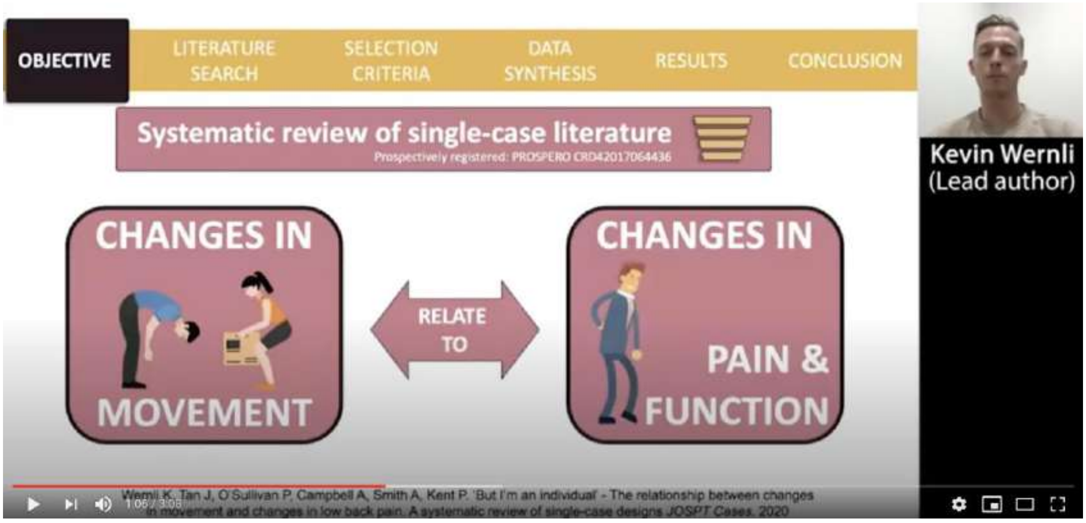
Brief video abstract: https://youtu.be/yFesgTlZynM

A.1.2 Chapter 4: Systematic review: Single-case designs

Figure 8-2 Infographic. Systematic review: Single-case designs



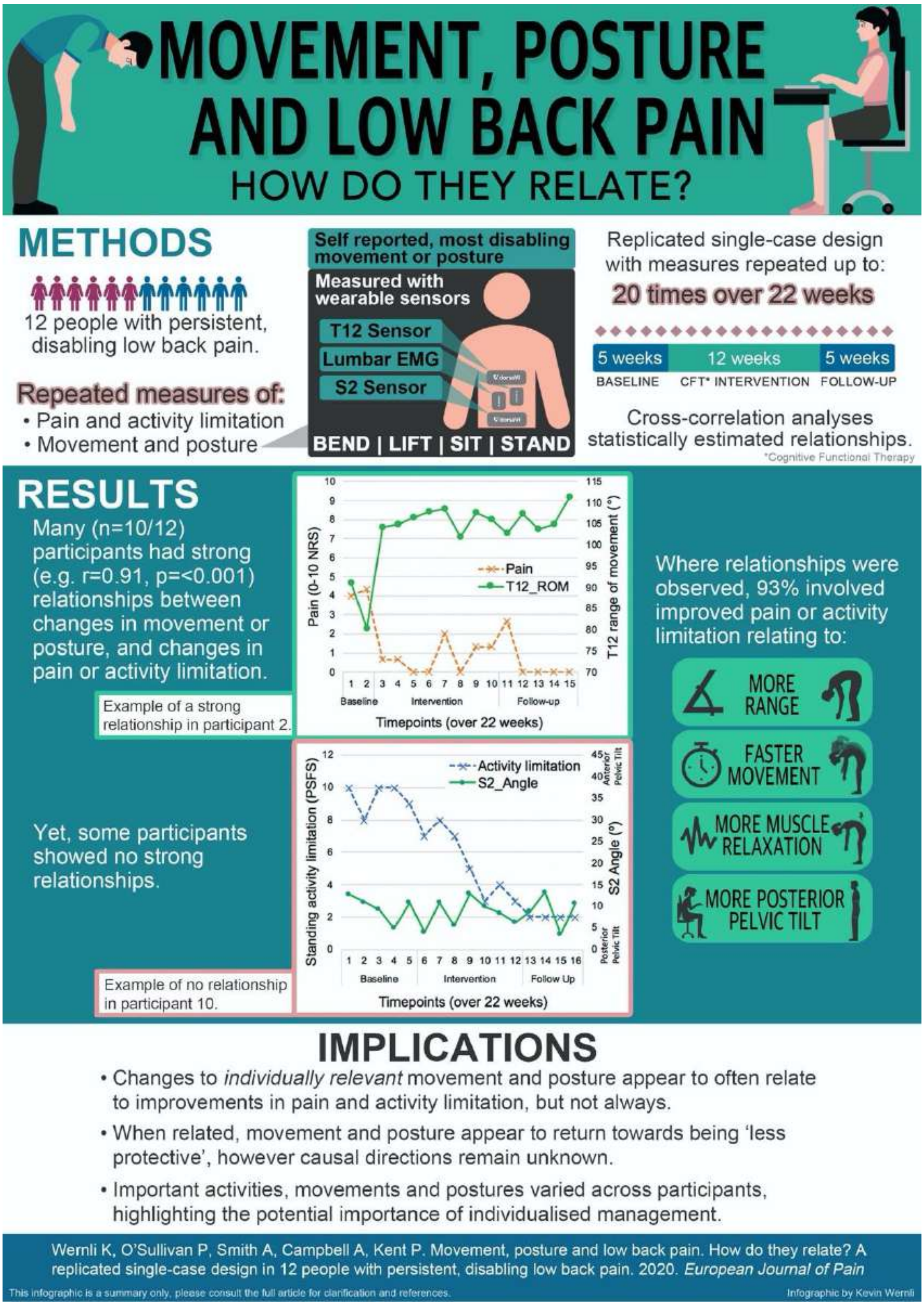
Video abstract:



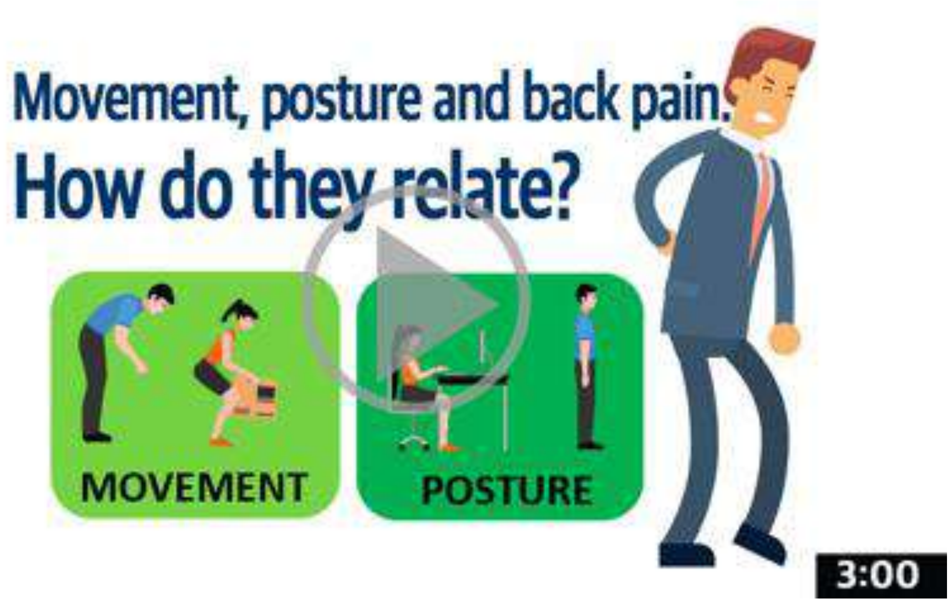
https://youtu.be/830RoPmFcbM

A.1.3 Chapter 5: Single-case series

Figure 8-3 Infographic. Single-case series



Video abstract:



https://youtu.be/LL7Cnk3VgaA

A.2 Infographics, videos, or podcasts produced for co-authored publications

O'Sullivan, P., Caneiro, J. P., Sullivan, K., Lin, I., Bunzli, S., **Wernli, K.**, & Keeffe, M. (2019). Back to basics: 10 facts every person should know about back pain. *British Journal of Sports Medicine*. https://doi.org/10.1136/bjsports-2019-101611

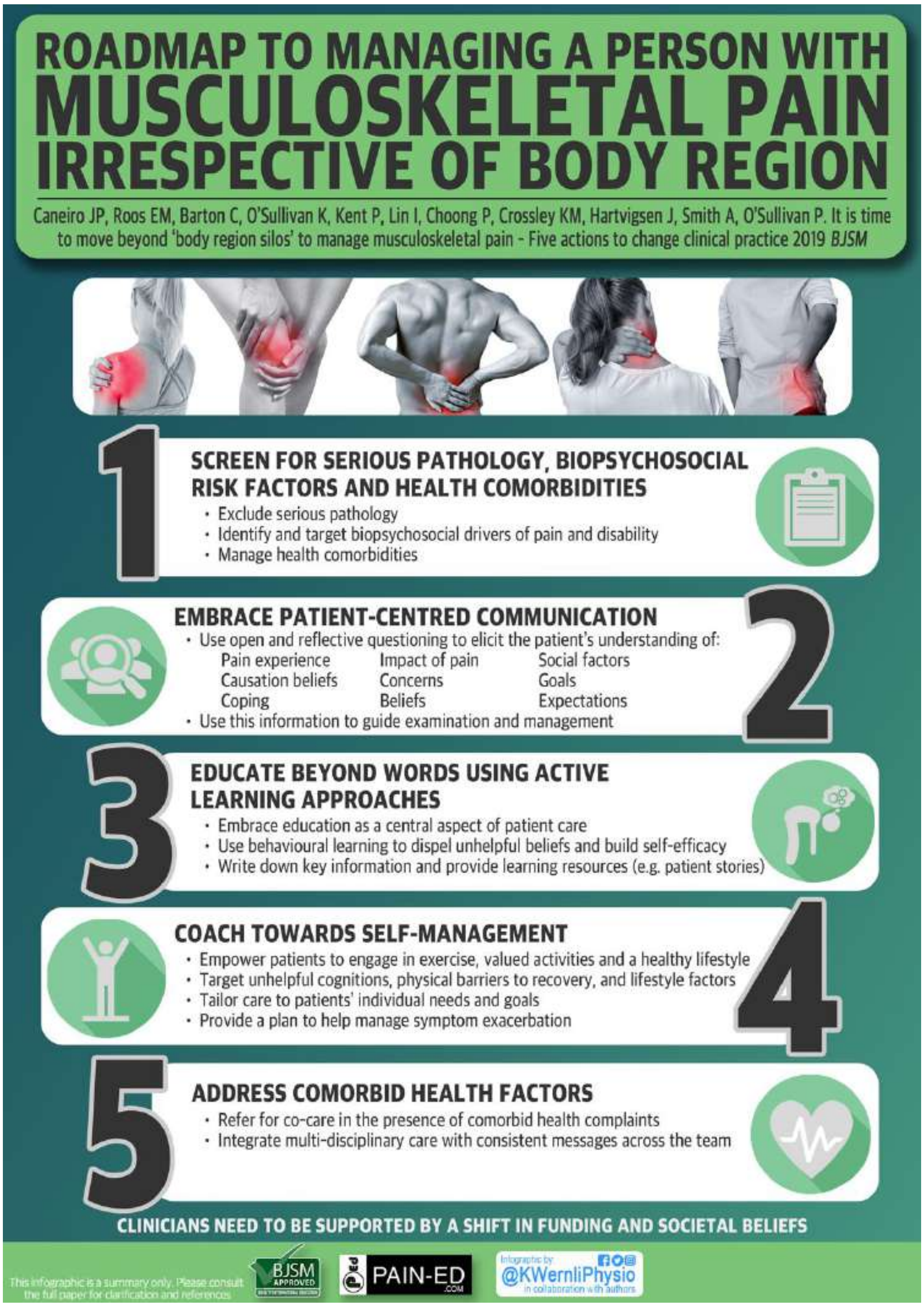
Figure 8-4 Back facts infographic

Videos: http://www.pain-ed.com/blog/2020/06/13/ten-low-back-pain-facts-videos/

Podcast: www.bodylogic.physio/podcast/trailer

Caneiro, J. P., Roos, E. M., Barton, C. J., Sullivan, K., Kent, P., Lin, I., Choong, P., Crossley, K. M., Hartvigsen, J., Smith, A. J., **Wernli, K.**, & O'Sullivan, P. B. (2020). Infographic. Roadmap to managing a person with musculoskeletal pain irrespective of body region. *British Journal of Sports Medicine, 54*(9), 554. https://doi.org/10.1136/bjsports-2019-101681

Figure 8-5 Roadmap to managing musculoskeletal pain infographic



Appendix B Research commercialisation prize

I attended a Research Commercialisation Program once a week for four weeks in June 2019. This program aimed to translate research findings to have outstanding social or economic impact. As part of this, I pitched a hypothetical app called ‘Back on Track’ that aimed to help people with back pain self-manage and get back to living using evidence-based strategies and collaborative approaches with clinicians. For this I was awarded a research commercialisation prize that included a scholarship valued at A$3,250 to attend Curtin Ignition, another commercialisation program.

No work presented in this thesis was commercialised.

Figure 8-6 Research commercialisation prize

Appendix C Evidence of ethical approval

Figure 8-7 Evidence of ethical approval

Curtin University

Office of Research and Development

GPO Box U1987
Perth Western Australia 6845

Telephone +61 8 9266 7863
Facsimile +61 8 9266 3793
Web research.curtin.edu.au

05-Oct-2017

Name: Peter Kent
Department/School: School of Physiotherapy and Exercise Science
Email: Peter.Kent@curtin.edu.au

Dear Peter Kent

RE: Ethics Office approval
Approval number: HRE2017-0706

Thank you for submitting your application to the Human Research Ethics Office for the project **An investigation of the relationship between movement and low back pain**.

Your application was reviewed through the Curtin University Low risk review process.

The review outcome is: **Approved**.

Your proposal meets the requirements described in the National Health and Medical Research Council's (NHMRC) *National Statement on Ethical Conduct in Human Research (2007).*

Approval is granted for a period of one ye ar from **05-Oct-2017** to **04-Oct-2018**. Continuation of approval will be granted on an annual basis following submission of an annual report.

Personnel authorised to work on this project:

Name	Role
Kent, Peter	CI
O'Sullivan, Peter	Co-Inv
Campbell, Amity	Co-Inv
Smith, Anne	Co-Inv
Wernli, Kevin	Student

Approved documents:

Document

Standard conditions of approval

Appendix D Supplementary files for the single-case series

D.1 Participant information sheet

Figure 8-8 Participant information sheet

Human Research Ethics Committee

Curtin University

PARTICIPANT INFORMATION SHEET

HREC Project Number	HRE2017-0706
Project Title	'An investigation of the relationship between movement and low back pain'
Principal Investigator	Associate Professor Peter Kent, *PhD Supervisor*
Researcher	Mr Kevin Wernli, *PhD Candidate*
Co-investigators	Professor Peter O'Sullivan, *PhD Co-supervisor* Dr Amity Campbell, *PhD Associate supervisor* Professor Anne Smith, *PhD Associate supervisor*
Version Number	Version 8
Version Date	4th April 2019

Curtin University Human Research Ethics Committee (HREC) has approved this study (HREC number: HRE2017-0706). Should you wish to discuss the study with someone not directly involved, in particular, any matters concerning the conduct of the study or your rights as a participant, or you wish to make a confidential complaint, you may contact the Ethics Officer on (08) 9266 9223 or the Manager, Research Integrity on (08) 9266 7093 or email hrec@curtin.edu.au

What is this project about?

- We know that persistent low back pain affects many aspects of people's lives. For some people, it can result in distress and in many cases, stop people from doing things that bring meaning to their lives, such as remaining active, going to work, playing with their kids and socialising. It can make the simplest tasks difficult and can result in some people changing the way they move to try and limit the amount of pain they experience, which can also result in avoiding certain tasks all together.
- Despite the best efforts from healthcare professionals (doctors, physiotherapists, psychologists, rehabilitation specialists etc.), treatments are sometimes not very effective in improving this condition over the long term. A possible reason for this is because most treatments attempt to change the symptom of pain and do not adequately address the underlying causes of pain, which can be very different for each individual.
- Recently however, a treatment approach that looks at each patient from an individual perspective, and teaches them to think, move and respond to pain differently, has been very successful at improving pain and function in many people with persistent and disabling low back pain. Better yet, for many, this improvement has been shown to last!
- A key aspect of this treatment is teaching individuals to move and posture themselves in different ways, which can often have a positive effect on their pain, however we don't fully understand what the relationship with movement and pain is. Also, we don't really know how movement influences people's pain-related thoughts and feelings.
- To understand this relationship, our project will provide you with this individualised treatment for your low back pain, and closely track how you move before, during and after the treatment.
- This project will help inform health care practitioners about how movement influences pain, disability and peoples' pain-related thoughts and feelings, leading to better care of individuals with this quite common condition.
- This project will include 12 adults (6 women and 6 men).

Who is doing the research?

- The project is being conducted by the PhD candidate Kevin Wernli and his supervisors – Associate Professor Peter Kent, Professor Peter O'Sullivan, Dr Amity Campbell and Professor Anne Smith.
- The results of this research are part of Kevin Wernli's study towards being awarded a Doctor of Philosophy at Curtin University and he is funded by the university and the Physiotherapy Research Fund.

Is there a financial cost involved?

- No, there is no cost involved. You will not have to pay for the treatment and you will not be paid to participate in the research.

Why am I being asked and what do I have to do?

- You are being asked to take part because you have the health condition we are interested in studying and helping (persistent, disabling low back pain).
- Your participation will involve having your movement assessed with small wearable wireless sensors, completing questionnaires, receiving physiotherapy treatment, and being interviewed about your thoughts, feelings and beliefs about how movement and posture influence low back pain. The main study period will take 22 weeks overall, 5 weeks before the treatment where we simply measure your movement and you fill out the questionnaires, 12 weeks where you will receive the treatment, we measure your movement and you fill out the questionnaires, and 5 weeks after the treatment where we again only measure your movement and you will fill out the questionnaires. A summary is provided below:
    - **Movement** – Frequent measures of your movement will be collected with the sensors most weeks throughout the study. This will be collected at a physiotherapy clinic in Shenton Park. The session will take approximately 30 minutes and we will endeavour to find a time that is convenient for you. You may also be required to wear the sensors (slightly smaller than a matchbox and half the thickness) on your back for the rest of the day following this assessment session, remove them at the end of your day and post them back to us the following day. You will not have to pay for postage. Most people say they hardly notice the sensors throughout their day. This movement assessment session will also be video/audio recorded. During the last assessment session before your initial treatment, you will be asked questions about your experience in the study so far. Nine months after the completion of the study, you will be required to attend the physiotherapy clinic in Shenton Park to have your movement measured for the long term follow-up.
    - **Questionnaires** – You will be asked to complete three types of questionnaires online, a short one (~5mins) completed most weeks for the duration of the study, a longer one (~20mins) to be completed on 3 occasions over the course of the study, and a one off, brief questionnaire completed prior to the study commencing (~5mins). All of the questionnaires can be completed online from anywhere with internet access (such as your own home) and you will receive an email reminder with an internet link to complete them on each occasion.
        - **Short questionnaire (~5mins)** – Completed 20 times over the 22 weeks, this questionnaire contains questions related to your thoughts and feelings about back pain. Each question is scored on a scale from 0 to 10 (the meaning for the scores in each question will be displayed in the questionnaire).

    - **Long questionnaire (~20mins)** – Completed 3 time over the 22 weeks, this questionnaire is made up of six questionnaires that provide a more in-depth assessment of your thoughts, feelings and reactions to pain, and how much your pain impacts on your life.
    - **Pre-study questionnaire (~5mins)** – Completed once before the study commences. This contains questions relating to your background and history of back pain.
    - **Long-term follow-up long and short term questionnaire (~25mins)** – Completed once, nine months after you complete the main study period. This includes questions on what and how much you feel has changed following the study.
  - **Treatment –** You will receive treatment from physiotherapists who have extensive experience treating patients with persistent and disabling low back pain problems at a Shenton Park clinic. We have allowed for 10 treatment sessions over the 12 weeks. The initial treatment session will last 60-90 minutes and will be video/audio recorded, while follow-up treatment sessions will last 30-45minutes and may also be video/audio recorded. We will endeavour to time these treatment sessions such that they occur after your movement assessment session, so you will only have to attend the clinic once per week. It is not uncommon for people to improve such that they don't require all 10 treatment sessions. If you and your treating physiotherapist decide that this is the case, then you will only be required to attend the clinic for the movement assessment sessions. The treatment will involve:
    - **Education** – the physiotherapist will listen to your story, what you have been told so far and what you think about your back. They will give you information about pain and all factors that can contribute to it, and help you make sense of it to better manage your problem. If you have had imaging (such as MRI's or X-Rays), these will be explained to you in the context of your back pain experience.
    - **Specific movement training** – the physiotherapist will look at the movements and postures in which you experience pain, or that you avoid doing because of pain and/or fear, and train a new way of moving with strategies to control the pain. The physiotherapist will also help you progress these activities so you can incorporate them into your daily life.
    - **Lifestyle and physical activity training** – you will be assisted to increase your physical activity levels as part of your management plan. You will be given exercises to do at home which will be progressed over time.
  - **Interviews –** These will occur on three occasions over the course of the study – at the start, after your first treatment session, and at the end of the treatment period. Interviews will explore your thoughts and feelings about the relationship between movement and low back pain. You will be asked questions such as *"Can you tell me about your thoughts about movement and back pain in general?"* and *"do you think the way you move and posture yourself influences your pain?"*. Each interview takes 30-45 minutes. During the interview, we will make a digital audio recording so we can concentrate on what you have to say and not be distracted by taking notes. After the interview, we will make a full written copy of the recording which we can send to you so that you can verify it.

Where do I have to go?

The movement assessments and the treatments in the study will take place at **Body Logic Physiotherapy** (215 Nicholson Rd, Shenton Park, 6008). The interviews will take place at a location convenient for you (for example your home, a local library or at the clinic).

How much time is required for each aspect of the study?

The study has three stages:

- **Before treatment** (5 weeks)
    - Responding 5 times (weekly) to a short online questionnaire (5 minutes each)
    - Responding twice (week 1 and week 5) to a longer online questionnaire (20 minutes each)
    - Attend the clinic 5 times (weekly) for a movement assessment session (30 minutes each)
    - Participate in an interview (30-45 minutes)
- **During treatment** (12 weeks)
    - Respond 10 times (most weeks) to a short online questionnaire (5 minutes each)
    - Attend the clinic 10 times for movement assessment sessions (30 minutes each)
    - Attend the clinic for up to 10 physiotherapy treatment sessions (initial session 60-90 mins, follow up sessions 30-45 minutes each) – we will endeavour to schedule this directly after the movement assessment session.
    - Participate in one interview (30-45 minutes)
- **After treatment** (5 weeks)
    - Respond 5 times (weekly) to a short online questionnaire (5 minutes each)
    - Respond once to a longer online questionnaire (20 minutes)
    - Attend the clinic 5 times (weekly) for a movement assessment session (30 minutes each).
    - Participate in an interview (30-45 minutes)

Total time commitment: estimated 17-22 hours over 22 weeks.

			A: Baseline (5 weeks)					B: Intervention (12 weeks)												A: Follow up (5 weeks & 9 months)					
Week			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	9m
Task	Time	Location																							
Movement assessment session	30 mins	Clinic	x	x	x	x	x	x	x	x	x	x	x	x	x		x		x	x	x	x	x	x	x
Attend treatment	60mins initial, 30mins follow up	Clinic						x	x	x	x	x	x	x	x		x		x						
Short online questionnaire	5 mins	Home	x	x	x	x	x	x	x	x	x	x	x	x	x		x		x	x	x	x	x	x	x
Longer online questionnaire	30 mins	Home	x				x													x					x
Interview	30mins	Home	x					x												x					

Are there any benefits to being in the research project?

- You will receive physiotherapy treatment from highly qualified physiotherapists who have taken the extra training required for them to be part of this study. The treatment you will receive has been previously demonstrated to be effective in reducing pain and disability. You will also have the opportunity to discuss your opinions and feelings about your condition and how it has affected your life.
- A previous participant in a similar Curtin University project reported *"I have gotten so much more out of being a participant in this study than I could have ever given to the researchers"*.
- We anticipate the results of this research will allow us to:
    - Improve the knowledge we have about this health condition.
    - Inform health care practitioners about how movement influences pain and disability, which may lead to better ways of managing people with the same health condition as you.
    - Inform future research in persistent low back pain.

Are there any risks, discomforts or inconveniences from being in the research project?

- We acknowledge this study demands your participation on many occasions. We will do our best to make the sessions fit your timetable and appreciate that you may have to take time off work, study or personal time to attend the clinic and respond to the questionnaires. We have taken care to minimise any risks or inconveniences associated with taking part in the study. Here are the potential inconveniences or discomforts associated with taking part in the study:
  - For the **movement assessment sessions,** we will be asking you to perform 3 repetitions of movements/postures that you may have difficulty performing. You may experience some discomfort during these and you a free to withdraw from testing at any time. While these are typically tasks that are performed many times throughout the day (such as bending over to pick something up, sitting or standing, or standing up from a chair/bed), we acknowledge that these will be performed for 5 weeks before you receive treatment to help improve them, this is in order to establish a clear picture of how you habitually move/posture yourself. It is important to note that the researcher conducting the study is a qualified physiotherapist who will be present during all the testing and can provide assistance if you need it. Also, the movement sensors are applied to your back by using hypoallergenic adhesive pads, and while it is rare, this may cause some minor skin irritation. Standard procedures when collecting surface electromyography (muscle signals) includes shaving of the area (with a disposable razor), using an alcohol wipe and light exfoliation/abrasion of the skin where the sensor is to be placed to maximise the signal. While not generally painful, the exfoliation (removal of dead skin cells) may cause some minor discomfort.
  - For the **online questionnaires,** we have been careful to make sure that the questions do not cause you any distress. We commonly use these questions with our patients in the clinic and in studies of pain. If the questions cause you any concerns or upset you, please contact the researcher Kevin Wernli immediately and he will advise accordingly.
  - For the **interviews**, we have been careful to make sure that the questions do not cause you any distress. If you feel concerned about any of these questions, you do not need to answer them. If the questions cause any concerns or upset you, we can refer you to a counsellor.
- The procedures selected have been used by the supervisors of this study in previous projects, and followed established protocols that minimize the risk, discomfort and inconvenience to you. Should you have any unforeseen problems (such as a skin irritation), we will refer you to your GP (or a GP we trust, if you don't have one).

Who will have access to my information?

- The information collected in this research will be re-identifiable (coded). This means that we will remove all personally identifying information on all data and replace it with a code. Only the research team will have access to the code to match your name, if it is necessary to do so. Any information we collect will be treated as confidential and used only in this project. The only people that will have access to your information are the research team (student and supervisors) and the Ethics Committee at Curtin University.
- *How will information be stored?* Electronic data will be password-protected and hard copy data (including video or audio tapes) will be kept in locked storage on campus (the PhD research student's locked file cabinet). This file cabinet is located at the Higher Degree by Research Hub at Curtin University, Bentley.
- *How long will the information be stored and what happens at the end of the storage period?* The information we collect in this study will be kept under secure conditions at Curtin

University for 7 years after the research has ended and then it will be destroyed.

- You have the right to access, and request correction of, your information in accordance with relevant privacy laws.
- The results of this research may be presented at conferences or published in professional journals but you will not be identified in any results that are published or presented.

Will you tell me the results of the research?

- Yes. We will write to you at the end of the research (about 6-8 months after the end of the study) and provide you with a personalised report containing the results from your participation.
- We will also inform you of all publications of the results of the research.

Do I have to take part in the research project?

Taking part in a research project is voluntary. It is your choice to take part or not. You do not have to agree if you do not want to. If you decide to take part and then change your mind, that is okay, you can withdraw from the project. You do not have to give us a reason; just tell us that you want to stop. Please let us know you want to stop, so we can make sure you are aware of anything that needs to be done so you can withdraw safely. If you chose to leave the study we will use any information already collected, unless you tell us not to.

What happens next and who can I contact about the research?

- Should you have any questions about the research, please contact the researcher, **Mr Kevin Wernli** at kevin.wernli@postgrad.curtin.edu.au **or** on ( ) to obtain further information or ask questions.
- If you decide to take part in this research we will ask you to sign a consent form. By signing it, you are telling us that you understand what you have read and what has been discussed. Signing the consent form indicates that you agree to be in the research project and have your health information used as described. Please take your time and ask any questions you have before you decide what to do. You will be given a copy of this information and the consent form to keep.

D.2 Consent form

Figure 8-9 Consent form

Movement and low back pain

Curtin University

CONSENT FORM

Curtin University Human Research Ethics Committee (HREC) has approved this study (HREC number HRE2017-0706). Should you wish to discuss the study with someone not directly involved, in particular, any matters concerning the conduct of the study or your rights as a participant, or you wish to make a confidential complaint, you may contact the Ethics Officer on (08) 9266 9223 or the Manager, Research Integrity on (08) 9266 7093 or email hrec@curtin.edu.au

HREC Project Number	HRE2017-0706
Project Title	"An investigation of the relationship between movement and low back pain"
Principal Investigator	Associate Professor Peter Kent, *PhD Supervisor*
Researcher	Mr Kevin Wernli, *PhD Candidate*
Co-investigators	Professor Peter O'Sullivan, *PhD Co-supervisor* Dr Amity Campbell, *PhD Associate supervisor* Associate Professor Anne Smith, *PhD Associate supervisor*
Version Number	Version 2
Version Date	16th January 2018

- I have read the participant information sheet and I understand its contents
- I believe I understand the purpose, extent and possible risks of my involvement in this project.
- I voluntarily consent to take part in this research project.
- I have had an opportunity to ask questions and I am satisfied with the answers I have received.
- I understand that this project has been approved by Curtin University Human Research Ethics Committee and will be carried out in line with the National Statement on Ethical Conduct in Human Research (2007) – updated May 2015.
- I understand that I will receive a copy of this Consent Form and the Participant Information Sheet.

Participant Name	
Participant Signature	
Date	

Declaration by researcher: I have supplied a Participant Information Sheet and Consent Form to the participant who has signed above, and believe they understand the purpose, extent and possible risks of their involvement in this project.

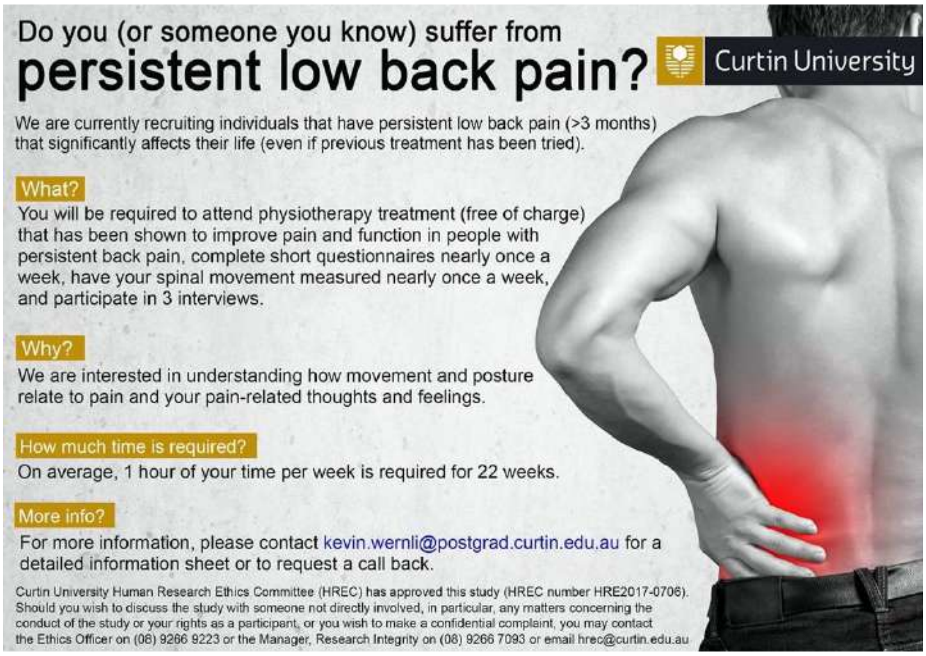
Researcher Name	**Kevin Wernli**
Researcher Signature	
Date	

Consent Form Version 2 16th January 2018

D.3 Recruitment materials

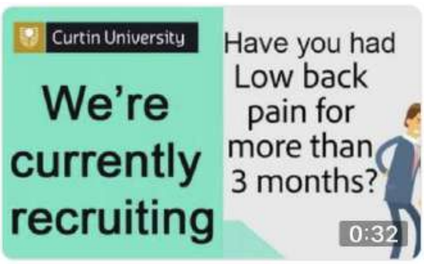
D.3.1 Poster

Figure 8-10 Recruitment poster



D.3.2 Recruitment videos

Short recruitment video:



https://youtu.be/YejxpOserYo

Longer recruitment video:

https://youtu.be/EPOOthFMP5M

D.4 Short questionnaires

Figure 8-11 Short questionnaires

Low back pain study - Short questionnaire

Details

Block 1

How would you rate your pain (0 = No pain, 10 = Pain as bad as it could be)?

	No pain										Pain as bad as it could be
	0	1	2	3	4	5	6	7	8	9	10
Currently?	○	○	○	○	○	○	○	○	○	○	○
On **average** over the last week?	○	○	○	○	○	○	○	○	○	○	○
At **worst** over the last week?	○	○	○	○	○	○	○	○	○	○	○

Over the last week (0 = Not at all, 10 = A great deal):

	Not at all										A great deal
	0	1	2	3	4	5	6	7	8	9	10
How much has the pain limited your usual activities or changed your daily routine for more than one day?	○	○	○	○	○	○	○	○	○	○	○

Over the last week (0 = Not at all, 10 = Extremely):

	Not at all										Extremely
	0	1	2	3	4	5	6	7	8	9	10
How bothersome has your back pain been?	○	○	○	○	○	○	○	○	○	○	○

Block 2

Please rate how well you are able to perform your patient specific activities over the last week (0 = Able to perform at same level as before pain/problem, 10 = Unable to perform activity).

	Able to perform at same level as before pain/problem										Unable to perform activity
	0	1	2	3	4	5	6	7	8	9	10
Lifting	○	○	○	○	○	○	○	○	○	○	○
Vacuuming	○	○	○	○	○	○	○	○	○	○	○
Walking	○	○	○	○	○	○	○	○	○	○	○
Bending with a round back	○	○	○	○	○	○	○	○	○	○	○

Please rate how fearful you are of performing those activities (0 = No fear, 10 = Very fearful).

	No fear										Very fearful
	0	1	2	3	4	5	6	7	8	9	10
Lifting	○	○	○	○	○	○	○	○	○	○	○
Vacuuming	○	○	○	○	○	○	○	○	○	○	○
Walking	○	○	○	○	○	○	○	○	○	○	○
Bending with a round back	○	○	○	○	○	○	○	○	○	○	○

Block 3

Please answer the statements below describing your beliefs over the last week (0 = Completely disagree, 10 = completely agree).

	Completely disagree 0	1	2	3	4	5	6	7	8	9	Completely agree 10
I believe physical activity will harm my back	○	○	○	○	○	○	○	○	○	○	○
I believe I should not do physical activities which (might) make my pain worse	○	○	○	○	○	○	○	○	○	○	○

Please answer the statements below describing how confident you are that you could do these activities over the last week (not *whether or not* you have been doing these things). 0 = Not at all confident, 10 = Completely confident.

	Not at all confident 0	1	2	3	4	5	6	7	8	9	Completely confident 10
I can do some form of work, despite the pain (work includes housework and paid/unpaid work)	○	○	○	○	○	○	○	○	○	○	○
I can live a normal lifestyle despite the pain	○	○	○	○	○	○	○	○	○	○	○

Please answer the statements below describing how often you did this over the last week (0 = Never did that, 10 = Always did that).

	Never do that 0	1	2	3	4	5	6	7	8	9	Always do that 10
When I felt pain, it was terrible and I thought it was never going to get any better	○	○	○	○	○	○	○	○	○	○	○
When I feel pain, I feel I can't stand it anymore	○	○	○	○	○	○	○	○	○	○	○

Please answer the statements below describing how often you did this over the last week (0 = Not at all, 10 = All the time).

	Not at all 0	1	2	3	4	5	6	7	8	9	All the time 10
When performing everyday tasks, I was **not** sure exactly what position my back was in	○	○	○	○	○	○	○	○	○	○	○
I couldn't perceive the exact outline of my back	○	○	○	○	○	○	○	○	○	○	○

Please answer the statements below describing how much control you feel you had over the last week (0 = No control, 10 = Full control).

	No control 0	1	2	3	4	5	6	7	8	9	Full control 10
How much control do you feel you had over your pain?	○	○	○	○	○	○	○	○	○	○	○
If you have a pain flare, how much control do you feel you have to decrease your pain?	○	○	○	○	○	○	○	○	○	○	○
How much do you believe you had control over the effects of pain on your life?	○	○	○	○	○	○	○	○	○	○	○

Please answer the statements below regarding your beliefs over the last week (0 = Completely disagree, 10 = Completely agree).

	Completely disagree 0	1	2	3	4	5	6	7	8	9	Completely agree 10
It is easy to injure your back	○	○	○	○	○	○	○	○	○	○	○
You could injure your back if you are not careful	○	○	○	○	○	○	○	○	○	○	○

Block 4

Please answer the below statements (0 = Completely disagree, 10 = completely agree).

	Completely disagree 0	1	2	3	4	5	6	7	8	9	Completely agree 10
I have control over the movement and/or position of my back	○	○	○	○	○	○	○	○	○	○	○
Controlling the movement and/or position of my back gives me control over my pain	○	○	○	○	○	○	○	○	○	○	○

Please answer the statement below (0 = No trust, 10 = Complete trust).

	No trust 0	1	2	3	4	5	6	7	8	9	Complete trust 10
I trust my back	○	○	○	○	○	○	○	○	○	○	○

Please detail any changes, progress, flares, thoughts or other life events that you think are important for us to know over the last week. These may be related or unrelated to your back (if none, please leave blank):

Low back pain study - Short questionnaire

D.5 Long questionnaires

Figure 8-12 Long questionnaires

13/06/2021 Qualtrics Survey Software

Low back pain study - Long questionnaire

Details

Please enter your initials:

Please enter today's date (DDMMYYY):

Please enter the study week from 1-22: (eg "5")

RMDQ - Block 1

This list contains some sentences that people have used to describe themselves when they have back pain. When you read them, you may find that some stand out because they describe your situation today. As you read the list, think of yourself today. When you read a sentence that describes your situation today, select 'yes'. If the sentence does not describe your situation, then select 'no' and go on to the next one. Remember, only select 'yes' to the sentence if you are sure that it describes your situation today.

	No	Yes
1. I stay at home most of the time because of my back problem or leg pain (sciatica)	○	○
2. I change position frequently to try and get my back or leg comfortable	○	○
3. I walk more slowly than usual because of my back problem or leg pain (sciatica)	○	○
4. Because of my back problem or leg pain (sciatica), I am not doing any of the jobs that I usually do around the house.	○	○
5. Because of my back problem or leg pain (sciatica), I use a handrail to get upstairs	○	○
6. Because of my back problem or leg pain (sciatica), I have to hold onto something to get out of an easy chair	○	○
7. I get dressed more slowly than usual because of my back problem or leg pain (sciatica)	○	○
8. I only stand for short periods of time because of my back problem or leg pain (sciatica)	○	○
9. Because of my back problem or leg pain (sciatica) I try not to bend or kneel down	○	○
10. I find it difficult for me to get out of a chair because of my back problem or leg pain (sciatica)	○	○
11. My back or leg is painful almost all the time	○	○
12. I find it difficult to turn over in bed because of my back problem or leg pain (sciatica)	○	○
13. I have trouble putting on my sock (or stockings) because of the pain in my back or leg	○	○
14. I only walk short distances because of my back or leg pain (sciatica)	○	○
15. I sleep less well because of my back problem or leg pain (sciatica)	○	○
16. I avoid heavy jobs around the house because of my back problem or leg pain (sciatica)	○	○
17. Because of my back problem or leg pain (sciatica), I am more irritable and bad tempered with people than usual	○	○
18. Because of my back problem or leg pain (sciatica), I go upstairs more slowly than usual	○	○
19. I stay in bed for most of the time because of my back or leg pain (sciatica)	○	○
20. Because of my back problem or leg pain (sciatica), my sexual activity has decreased	○	○
21. I keep rubbing or holding areas of my body that hurt or are uncomfortable	○	○
22. Because of my back problem or leg pain (sciatica), I am doing less of the daily work around the house than I would usually do	○	○
23. I often express concern to other people over what might be happening to my health.	○	○

TSK - Block 2

https://curtin.au1.qualtrics.com/Q/EditSection/Blocks/Ajax/GetSurveyPrintPreview?ContextSurveyID=SV_3Ue2pnLDImEytJr&ContextLibraryID=UR_bDEvXfVP... 1/5

Please respond to the following 17 questions

	strongly disagree	disagree	agree	strongly agree
I'm afraid that I might injure myself if I exercise	○	○	○	○
If I were to try to overcome it, my pain would increase	○	○	○	○
My body is telling me I have something dangerously wrong	○	○	○	○
My pain would probably be relieved if I were to exercise	○	○	○	○
People aren't taking my medical condition seriously enough	○	○	○	○
My accident has put my body at risk for the rest of my life	○	○	○	○
Pain always means I have injured my body	○	○	○	○
Just because something aggravates my pain does not mean it is dangerous	○	○	○	○
I am afraid that I might injure myself accidentally	○	○	○	○
Simply being careful that I do not make any unnecessary movements is the safest thing I can do to prevent my pain from worsening	○	○	○	○
I wouldn't have this much pain if there weren't something potentially dangerous going on in my body	○	○	○	○
Although my condition is painful, I would be better off if I were physically active	○	○	○	○
Pain lets me know when to stop exercising so that I don't injure myself	○	○	○	○
It's really not safe for a person with a condition like mine to be physically active	○	○	○	○
I can't do all the things normal people do because it's too easy for me to get injured	○	○	○	○
Even though something is causing me a lot of pain, I don't think it's actually dangerous	○	○	○	○
No one should have to exercise when he/she is in pain	○	○	○	○

Pain Self-Efficacy - Block 3

Please rate how confident you are that you can do the following things <u>at present</u>, despite the pain. 0=Not at all confident, 6 = completely confident

	Not at all confident					Completely confident	
	0	1	2	3	4	5	6
I can enjoy things, despite the pain	○	○	○	○	○	○	○
I can do most of the household chores (e.g. tidying-up, washing dishes, etc.), despite the pain	○	○	○	○	○	○	○
I can socialise with my friends or family members as often as I used to do, despite the pain	○	○	○	○	○	○	○
I can cope with my pain in most situations	○	○	○	○	○	○	○
I can do some form of work, despite the pain ("work" includes housework, paid and unpaid work)	○	○	○	○	○	○	○
I can still do many of the things I enjoy doing, such as hobbies or leisure activity, despite pain	○	○	○	○	○	○	○
I can cope with my pain without medication	○	○	○	○	○	○	○
I can still accomplish most of my goals in life, despite the pain	○	○	○	○	○	○	○
I can live a normal lifestyle, despite the pain	○	○	○	○	○	○	○
I can gradually become more active, despite the pain	○	○	○	○	○	○	○

Halfway there ${m://FirstName}! Keep it up!

Pain Catastrophising Scale - Block 4

We are interested in the types of thoughts and feelings that you have when you are in pain. Listed below are thirteen statements describing different thoughts and feelings that may be associated with pain. Using the following scale, please indicate the degree to which you have these thoughts and feelings when you are experiencing pain.

	Not at all	To a slight degree	To a moderate degree	To a great degree	All the time
I worry all the time about whether the pain will end	○	○	○	○	○
I feel I can't go on	○	○	○	○	○
It's terrible and I think it's never going to get any better	○	○	○	○	○
It's awful and I feel that it overwhelms me	○	○	○	○	○
I feel I can't stand it anymore	○	○	○	○	○
I become afraid that the pain will get worse	○	○	○	○	○
I keep thinking of other painful events	○	○	○	○	○
I anxiously want the pain to go away	○	○	○	○	○
I can't seem to keep it out of my mind	○	○	○	○	○
I keep thinking about how much it hurts	○	○	○	○	○
I keep thinking about how badly I want the pain to stop	○	○	○	○	○
There's nothing I can do to reduce the intensity of the pain	○	○	○	○	○
I wonder whether something serious may happen	○	○	○	○	○

FreBAQ - Block 5

Here are some things which other patients have told us about how their back feels to them. Using the following scale please indicate the degree to which your back feels this way when you are experiencing back pain
Never = Never feels like that
Rarely = Rarely feels like that
Occasionally = Occassionally, or some of the time feels like that
Often = Often, or a moderate amount of time feels like that
Always = Always, or most of the time feels like that

	Never	Rarely	Occasionally	Often	Always
My back feels as though it is not part of the rest of my body	○	○	○	○	○
I need to focus all my attention on my back to make it move the way I want it to	○	○	○	○	○
I feel as if my back sometimes moves involuntarily, without my control	○	○	○	○	○
When performing everyday tasks, I **don't** know how much my back is moving	○	○	○	○	○
When performing everyday tasks, I am **not** sure exactly what position my back is in	○	○	○	○	○
I **can't** perceive the exact outline of my back	○	○	○	○	○
My back feels like it is enlarged (swollen)	○	○	○	○	○
My back feels like it has shrunk	○	○	○	○	○

	Never	Rarely	Occasionally	Often	Always
My back feels lopsided (asymmetrical)	○	○	○	○	○

BackPAQ - Block 6

These questions are about your own back. Please rate each statement

	False	Possibly false	Unsure	Possibly true	True
Your back is one of the strongest parts of your body	○	○	○	○	○
Your back is well designed for the way you use it in daily life	○	○	○	○	○
Bending your back is good for it	○	○	○	○	○
Sitting is bad for your back	○	○	○	○	○
Lifting without bending the knees is not safe for your back	○	○	○	○	○
It is easy to injure your back	○	○	○	○	○

These questions are about looking after your own back. Please rate each statement

	False	Possibly false	Unsure	Possibly true	True
It is important to have strong muscles to support your back	○	○	○	○	○
Good posture is important to protect your back	○	○	○	○	○
If you overuse your back, it will wear out	○	○	○	○	○
If an activity or movement causes back pain, you should avoid it in the future	○	○	○	○	○
You could injure your back if you are not careful	○	○	○	○	○
You can injure your back and only become aware of the injury sometime later	○	○	○	○	○

These questions are about back pain in general. Please rate each statement

	False	Possibly false	Unsure	Possibly true	True
Back pain means that you have injured your back	○	○	○	○	○
A twinge in your back can be the first sign of a serious injury	○	○	○	○	○
Thoughts and feelings can influence the intensity of back pain	○	○	○	○	○
Stress in your life (financial, work, relationship) can make back pain worse	○	○	○	○	○
When you have back pain, you can do things which increase your pain without harming the back	○	○	○	○	○
Having back pain makes it difficult to enjoy life	○	○	○	○	○
It is worse to have pain in your back than your arms or legs	○	○	○	○	○
It is hard to understand what back pain is like if you have never had it yourself	○	○	○	○	○

These questions are about what you should do if you have back pain. Please rate each statement

	False	Possibly false	Unsure	Possibly true	True
If your back hurts, you should take it easy until the pain goes away	○	○	○	○	○
If you ignore back pain, you may cause damage to your back	○	○	○	○	○
It is important to see a health professional when you have back pain	○	○	○	○	○
To effectively treat back pain you need to know exactly what is wrong	○	○	○	○	○
If you have back pain you should avoid exercise	○	○	○	○	○
When you have back pain the risks of vigorous exercise outweigh the benefits	○	○	○	○	○
If you have back pain you should try to stay active	○	○	○	○	○

These questions are about recovering from back pain. Please rate each statement

	False	Possibly false	Unsure	Possibly true	True
Most back pain settles quickly, at least enough to get on with normal activities	○	○	○	○	○
Worrying about your back can delay recovery from back pain	○	○	○	○	○
Focussing on things other than your back helps you to recover from back pain	○	○	○	○	○
Expecting your back pain to get better helps you to recover from back pain	○	○	○	○	○
Once you have had back pain there is always a weakness	○	○	○	○	○
There is a high chance that an episode of back pain will not resolve	○	○	○	○	○
Once you have a back problem, there is not a lot you can do about it	○	○	○	○	○

Low back pain study - Long questionnaire

Appendix E Permission to reproduce published material

E.1 Figure 2-1 The Common Sense Model.

Figure 2-1 The Common Sense Model (Leventhal et al., 1980) adapted to LBP (Bunzli et al., 2017).

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Appendix F Qualitative audit trail

F.1 Example of meeting frequency and agenda.

KW PhD Meeting 3rd March 2020	3 Mar 2020 at 3:38 pm	15 KB	Micros...(.docx)
KW PhD Meeting 17 March 2020	18 Mar 2020 at 5:18 pm	14 KB	Micros...(.docx)
KW PhD Meeting 31 March 2020	31 Mar 2020 at 4:03 pm	14 KB	Micros...(.docx)
KW PhD Meeting 14th April 2020	18 Apr 2020 at 1:11 pm	15 KB	Micros...(.docx)
KW PhD Meeting 28th April 2020	7 May 2020 at 12:24 pm	19 KB	Micros...(.docx)
KW Phd Meeting 12th May 2020	14 May 2020 at 7:59 pm	24 KB	Micros...(.docx)
KW PhD Meeting 26 May 2020	27 May 2020 at 12:10 pm	15 KB	Micros...(.docx)
KW PhD Meeting 9th of June 2019	10 Jun 2020 at 9:11 am	19 KB	Micros...(.docx)
KW PhD Meeting 30th June 2020	1 Jul 2020 at 2:24 pm	14 KB	Micros...(.docx)
KW PhD Meeting Monday 7th of July 2020	7 Jul 2020 at 5:21 pm	17 KB	Micros...(.docx)
KW PhD Meeting 21st Jul 2020	23 Jul 2020 at 11:20 am	15 KB	Micros...(.docx)
KW PhD Meeting 8th Sept 2020	8 Sep 2020 at 4:09 pm	15 KB	Micros...(.docx)
KW PhD Meeting 22Sep20	22 Sep 2020 at 11:51 am	19 KB	Micros...(.docx)
KW PhD Meeting 6th October 2020	7 Oct 2020 at 10:20 am	14 KB	Micros...(.docx)
KW PhD Meeting Quali with AS and POS SEPT20	10 Oct 2020 at 2:33 pm	14 KB	Micros...(.docx)
KW PhD Meeting 20th October 2020	20 Oct 2020 at 11:56 am	15 KB	Micros...(.docx)
KW PhD Meeting 17th November 2020	19 Nov 2020 at 5:22 pm	20 KB	Micros...(.docx)
KW PhD Meeting 1 Dec 2020	18 Dec 2020 at 5:09 pm	25 KB	Micros...(.docx)
KW PhD Meeting 12th of January 2021	13 Jan 2021 at 11:07 am	18 KB	Micros...(.docx)
KW PhD Meeting 2nd of February	4 Feb 2021 at 2:54 pm	18 KB	Micros...(.docx)
KW Meeting summary Mar 21	18 Mar 2021 at 6:36 am	18 KB	Micros...(.docx)
KW PhD meeting 15th MARCH 2021	18 Mar 2021 at 6:36 am	14 KB	Micros...(.docx)
KW Meeting 11MAY.docx	12 May 2021 at 10:10 am	18 KB	Micros...(.docx)
KW PhD Meeting 25th of May 2021.docx	25 May 2021 at 4:55 pm	20 KB	Micros...(.docx)
KW PhD Meeting 8th of June.docx	8 Jun 2021 at 3:09 pm	14 KB	Micros...(.docx)

KW PhD Meeting Quali with AS and POS

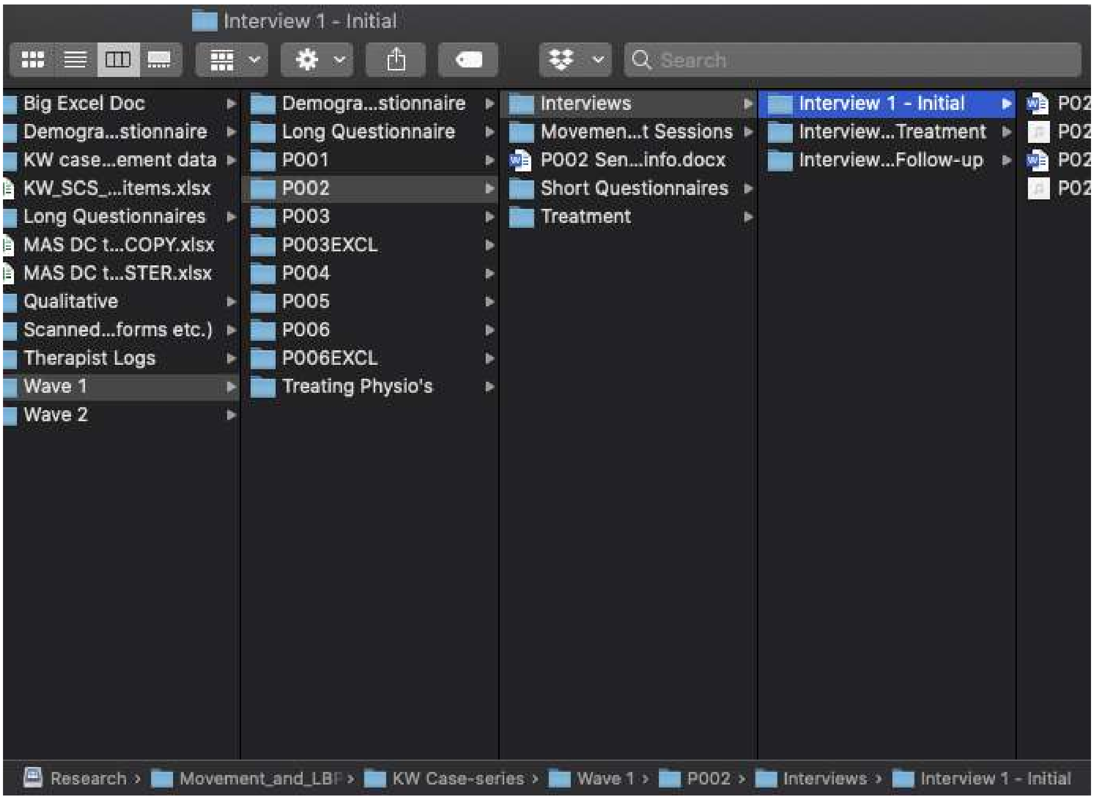
1. Added: 'greater understanding/less uncertainty' into code book under 'appraisal'
2. Removed (conflicting experiences, uncertainty) from APPRAISAL code.
3. I wonder if we need to somewhat have a section for emotions (i.e worry and fear) and how that influences movement and posture? Just keep it really simple and not go into the detail that the previous CSM did?
4. Is movements/postures as a recovery strategy an appraisal…?
5. Consciously change MP (action) is very similar to Change M/P/AL/Pain (LIVED EXPERIENCE)… One refers to movement as a strategy/response, the other refers to the experience or observation that MPs (or P/AL) has changed…
    a. Also very similar to movement/postures as a recovery strategy – I guess there are actions related to this (change MP), appraisals/lived experiences, and cognitions ("I used changing MPs as a recovery strategy")

This is Post 8th OCTOBER

6. Do we need a code for: trusted relationship/being shown what to do in individually tailored way?
    a. UPDATE – this is added under appraisal, as well as Being shown what to do and doing it is useful.
7. Not protecting (under Action/response), is similar to Moving freely/supple/flexible… (under lived experience).
8.

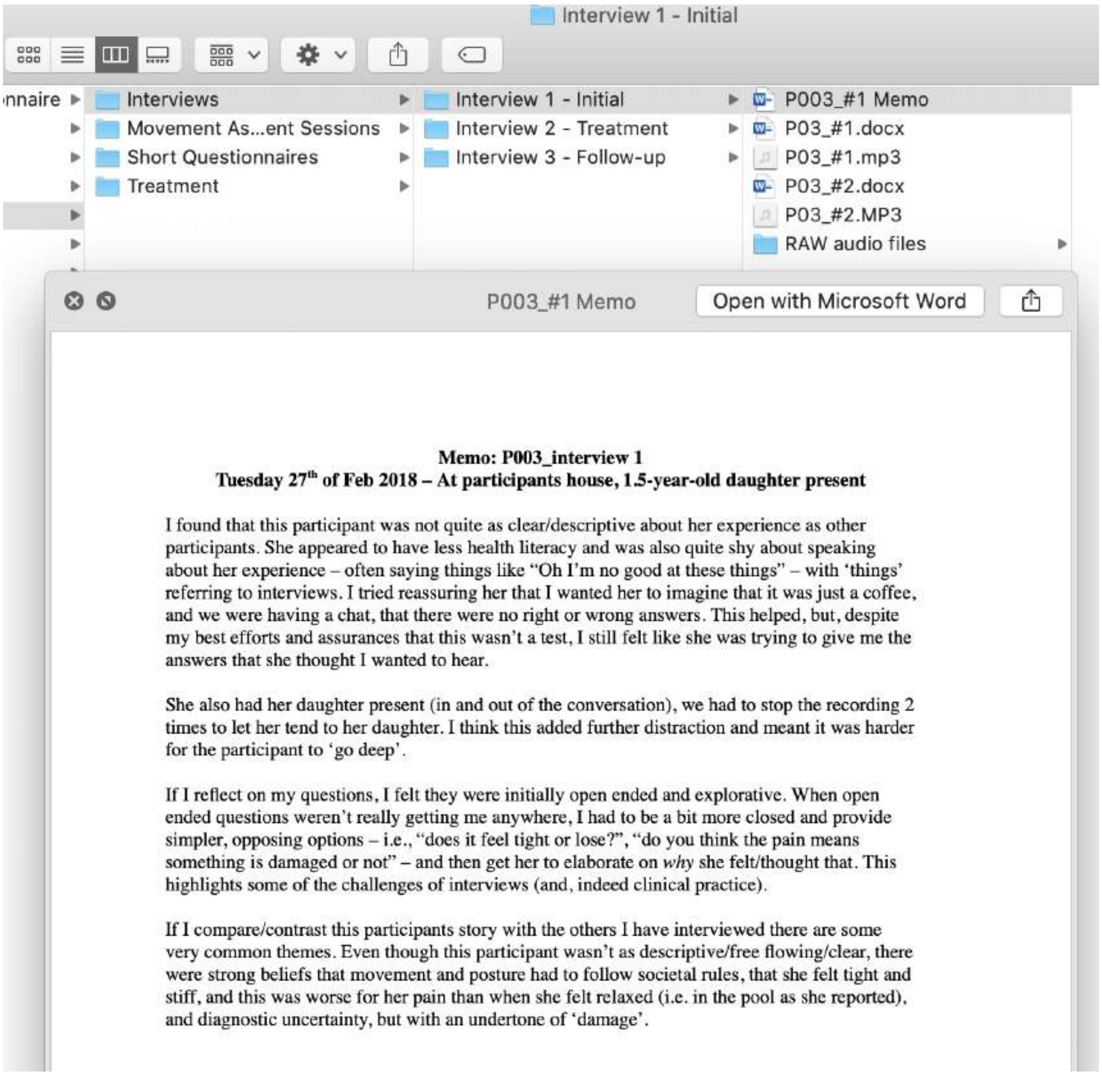
F.2 Data organisation

Data were saved in individual participant files. Each file contained the audio file and a verbatim transcript (with the reflexive memo for each transcript saved within the MAXQDA software).



F.3 Memos

Following the interviews



Memo: P003_interview 1
Tuesday 27th of Feb 2018 – At participants house, 1.5-year-old daughter present

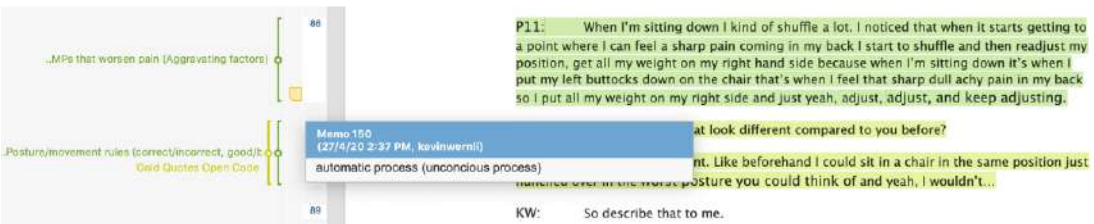
I found that this participant was not quite as clear/descriptive about her experience as other participants. She appeared to have less health literacy and was also quite shy about speaking about her experience – often saying things like "Oh I'm no good at these things" – with 'things' referring to interviews. I tried reassuring her that I wanted her to imagine that it was just a coffee, and we were having a chat, that there were no right or wrong answers. This helped, but, despite my best efforts and assurances that this wasn't a test, I still felt like she was trying to give me the answers that she thought I wanted to hear.

She also had her daughter present (in and out of the conversation), we had to stop the recording 2 times to let her tend to her daughter. I think this added further distraction and meant it was harder for the participant to 'go deep'.

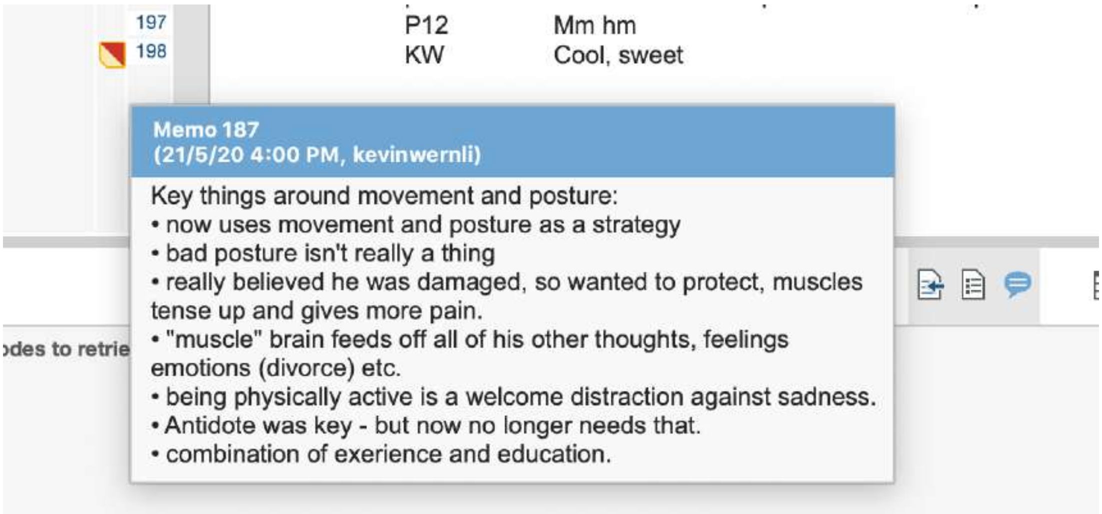
If I reflect on my questions, I felt they were initially open ended and explorative. When open ended questions weren't really getting me anywhere, I had to be a bit more closed and provide simpler, opposing options – i.e., "does it feel tight or lose?", "do you think the pain means something is damaged or not" – and then get her to elaborate on *why* she felt/thought that. This highlights some of the challenges of interviews (and, indeed clinical practice).

If I compare/contrast this participants story with the others I have interviewed there are some very common themes. Even though this participant wasn't as descriptive/free flowing/clear, there were strong beliefs that movement and posture had to follow societal rules, that she felt tight and stiff, and this was worse for her pain than when she felt relaxed (i.e. in the pool as she reported), and diagnostic uncertainty, but with an undertone of 'damage'.

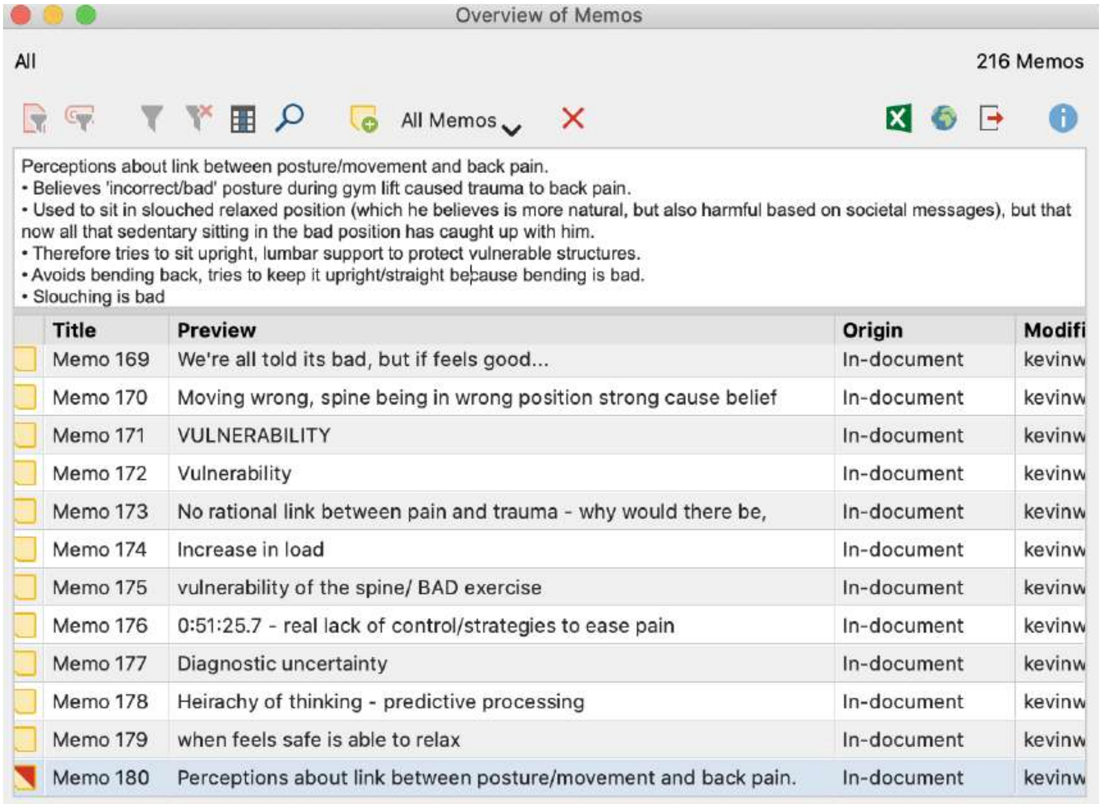
Throughout the transcript



Summary memo

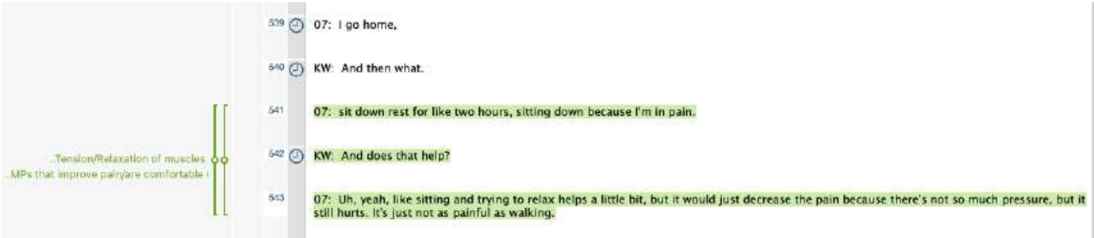


Overview of memo's



F.4 Coding and code book

Open coding in MAXQDA



Code system/code book

F.5 Peer review and cross coding

Example communication and summary from cross coding and peer review.

Coding for P01, P07 and P11

FC Fiona Coll

To: Kevin Wernli

Friday, 8 May 2020 at 3:43 pm

MAXQDA Summaries... 415.9 KB

Download All   Preview All

You replied to this message on 12/5/20, 10:04 am.   Show Reply

Hi Kev,

I hope you are going well and getting a little bit of sunshine today!

I have attached for each of the 3 participants and each of the 4 interviews: P## **Summary ## interview MEMO** which is looking at CAUSE/ WHY/ HOW/ PSYCHE FACTORS, and **P## Key Summary ## interview.**

I hope this system is easier to access some of the information you need. If you need more information please don't hesitate to tell me or you would like it done differently.

Hope fully see you soon.....let me know if you want to do a meeting to discuss.

thank you

Fiona

P01 Summary of interview MEMO #1.docx   Open with Microsoft Word

P01 # interview 1

CAUSE:

Her initial fall off the bike as a child and where she received no medical check-up or intervention. Doing excessive amount of sit ups when she was older caused another onset of pain. She has been told her "muscles are not doing the job they should be" which she recites not sure if she really believes this but I think she uses it has a default explanation?

HOW:

She finds sitting and lying helps her pain though walking if she does too much her pain comes on and feels she is generally slower with activity. She is aware that she is moving possibly in a dysfunctional way but has no picture of this in her mind.

WHY:

She is confused about how to move as she has been told her "muscles are not working how they should" though she is not put off doing activities she may just rest between a lot of walking.

PSYCH FACTORS:

She is very frustrated as she really does not believe "suddenly her muscles are not working well" she questions that wouldn't they adjust to her aging spinal structure. She wants someone to 'fix it" will do what it takes. She is uncertain what is going on. She has an anxiety of what happens if her pain keeps increasing as this seems to be the pattern. I think she is also desperate and fearful of the future but doesn't quite say that.

Her husband is keen to travel though 01 is not so keen due to her last experience and her LBP.

Interestingly she also talks of her near death experience overseas with her cardiac condition. Not only did she have surgery for her stents she died on the operating table but was revived, she also witnessed a woman on her ward die post op. She also had another episode of agina in Perth. I think this experience impacted on her Psyche tremendously.

An example of cross-coding

wer: How do you vacuum differently?

: I'm taking more caution on how I'm moving.

wer: What does that look like if you were to describe that to me?

: That's a hard one.

wer: Pretend I'm blind and we've got a videotape of you that three years ago and the
pe of you trying to vacuum now?

: Three years ago I would just pull and push the vacuum and get my job done. Now I sort
1 how I'm pulling the vacuum, watch how I am pulling the vacuum and sort of like lift the
a little bit more when I'm on the carpet areas.

wer: So your more careful?

: More.

wer: Do you feel you'd move your back differently?

: Yes.

wer: How?

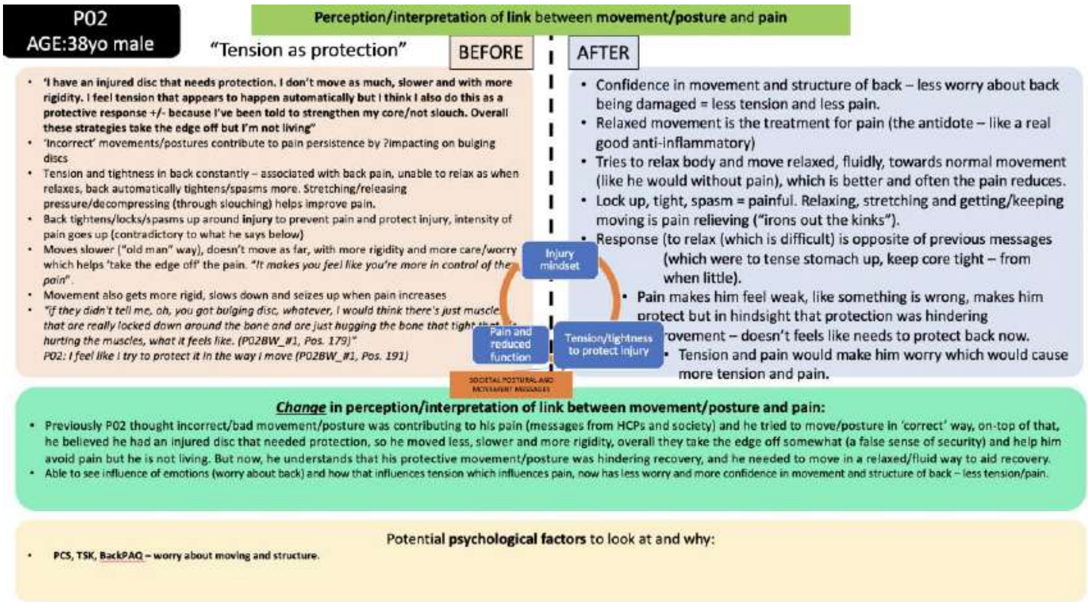
: I probably watch how I twist and turn to pull the vacuum.

Anne Smith
3.4 Protective/cautious/careful movement/posture
3.2 Consciously change MP
1.2 Change movement/posture/pain/al

Could come under any of these 3 as she describes changing movement consciously by being more cautious.
I don't think she has reflected on the Appraisal of this strategy here though

F.6 Summaries, theme development, and early figures

Summaries



Participant summaries Open with Microsoft Word

Participant	Key themes at baseline	Key themes at follow-up	Journey/Bridge
P01 – 76yo female 'Maureen'	• Beliefs that body broken (damaged or out of place) • Uncertainty surrounding cause, 'correct' posture. • Slow, protective, tense and careful movement to prevent further damage	• Maintenance of 'broken body' belief. • Continued uncertainty and confusion regarding link between movement/posture and pain. • Feels like moves and postures herself normally. • Recommended movements and postures conflict with psyche and feel unnatural	• No sustained lived experience of pain control with movement or postural strategies to facilitate learning
P02 – 38yo male 'Bradley'	• 'Moving incorrectly' (lifting incorrectly, twisting, jumping off utes) resulted in disc bulge. • Believes 'something is wrong', injured, damaged, back is stuffed, rotten and this is causing pain. • Movement/posture feels protective, rigid, slow, tight, seized up, avoidant (previously was free flowing, could bend, twist, run, jump, move without thinking, wasn't as scared to move) • Societal/HCP rules around posture (sit/sleep/lift) and importance of building core strength'. • Uncertain around cause, agg/ease, recovery. • Fear, frustration, low mood.	• Uses change in movement/posture (relaxed, soft belly, fluid) as strategy to control pain (surprisingly effective and simple). • Movement is now without hesitation, not jarring, and confident. • No longer worried about 'damaged structure'. • Pain has different and less threatening meaning – "it's not bad pain" • Recognition that societal rules (brace core, lifting) weren't helpful/trustworthy • Less frustration, fear, worry. Better mood.	• Lived experience of being able to control pain with movement, and control flares. • Updated understanding of condition, greater clarity, less worry and uncertainty. • Guidance from trusted HCP, with evidence of results, was important.
P03 – 40yo female 'Tara'	• Something is wrong with back. • 'Bad' posture makes pain worse • Uncertainty around pain • Cautious, tense, careful and protective movements.	• Changes movement (more range, less tension, through breathing) as a strategy for pain control • Being shown how to move in less protective way, and then experiencing it works, important.	• Being shown was important • Experiential learning that what was shown actually helped • Permission to 'break the postural rules'

Developing themes

KW PhD – Mixed Methods paper - Developing Themes

Research Question: How do people conceptualise relationships between posture/movement and pain/AL and how does this conceptualisation change after CFT intervention?

Broad Theme	Sub-theme/code contributing to theme
Lived experience with posture/movement and pain/AL (i.e things that hurt them or things they can't do - as well as experience of easing pain/positive experiences with movement and posture?) "EXPERIENCE"	9 Experiential Learning of link between MP and Pain/AL 5.2 MPs that improve pain/are comfortable (Easing factors) 6.3 MPs that worsen pain (Aggravating factors) 12.4 reduced/more movement (incl stiffness) 12.4.1 Moving freely/supple/flexible/normally linked to pain
Beliefs about pain "BELIEFS"	10 Other Body regions relating to LBP 11 Meaning of pain with movement/postures 14.2 Pain science 12.9 confidence to manage pain/condition
Beliefs about movement/posture "BELIEFS" including as informed by experiences/appraisals of experiences	14 Messages/belief (social, HCP, other) re: movement & posture 14.1 Posture/movement rules (correct/incorrect, good/bad, right/wrong 14.1.1 Pre intervention rule book 14.1.2 Post intervention rule book 14.3 Core exercises 14.4 Ergonomics/Occupational Health and Safety 14.5 Long-term history of being sedentary 6.1.1 MPs that cause damage to structures/irritate biology 6.2 Spine out of position/out of alignment linked to pain 5 MP as positive 5.1 Movements/postures as a recovery/management strategy 6 MPs as negative 6.1 MPs as a cause 6.4 Anticipation of pain with movements/postures 12.8 Movement confidence/less worry about movement 8.3 New insights into pre-treatment movement/postural strategies
Attempting to control/controlling pain through movement/posture "ACTION/RESPONSE"	12 Protective/cautious/careful movement/posture (OR NOT-PROTECTIVE 12.1 Due to not wanting to experience pain/functional loss 12.2 Due to fear of damage/vulnerable structures 12.3 Tension/Relaxation of muscles 12.3.1 Linked to pain 12.3.2 Tension linked to psychological state 12.5 Fidgeting, moving around 12.6 Breathing as a strategy 12.7 Not protecting 15 Avoidance of movements/postures 15.1 Damage 15.2 Functional loss 16 Conscious/unconcious Mvmt/Posture - ?awareness ?cognisant 16.1 MP unconcious 16.2 Conciously change MP 17 Pacing 8.1 Change movement/posture/pain/al 8.1.1 Functional gain (improved AL) 7.2 self-experimentation with movement/postures as a strategies
Conflicting experiences with attempts to control pain "APPRAISAL"	4 Contradictory belief
Uncertainty emerging from conflicting experiences "APPRAISAL"	7 uncertainty/unknown link bw pain/no pain with movement/posture 7.1 conflict between messages and belief 13 Movement/postural perception 13.1 Uncertainty of body position/sensations 13.2 MP different in reality than perception (body perception) 8.2 No change in movement/posture/pain/al

8 Change or not.

Kevin Werali
Not sure if this is the right terminology.

Kevin Werali
Unsure about this one...

Kevin Werali
Could consider merging these and just have beliefs ; divided into 'beliefs about pain' and 'beliefs about MPs'...?

Kevin Werali
I see the persons appraisal of whether the see movement/posture s negative or positive as more a *belief*, not as an attempt to control pain? Hence I have put these here under 'beliefs about movement/posture' and not under 'attempts to control pain' as discussed in the meeting

Kevin Werali
Not sure how this really fits – happy with changing movement as an action/attempt to control, but the appraisal of "I can now do more" doesn't seem to fit too well here...?

Kevin Werali
For me, this is too much detail for a 'broad' theme. This is really highlighted by a few codes within a few people (where they identify that slouching feels better, or that moving/walking eases their pain despite them saying their broken and need to protect. Or when they say they are protecting everything the way they should but still having pain.... On these occasions, I have coded them under ; MPs that ease/worsen pain – which for me is a lived experience.

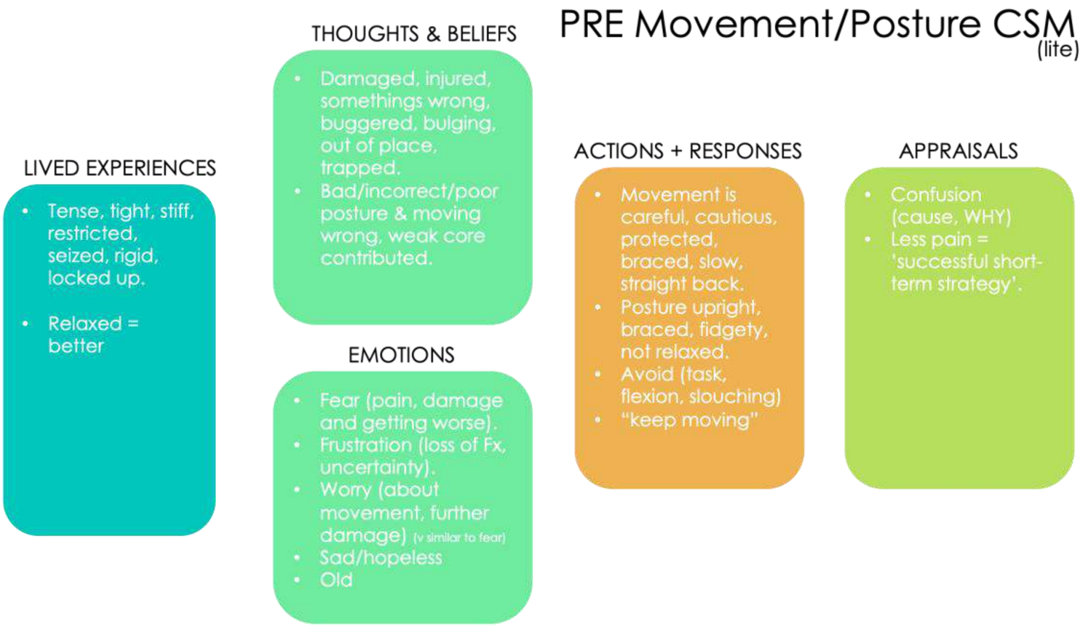
Kevin Werali
There's also not many codes that seem to fit here?

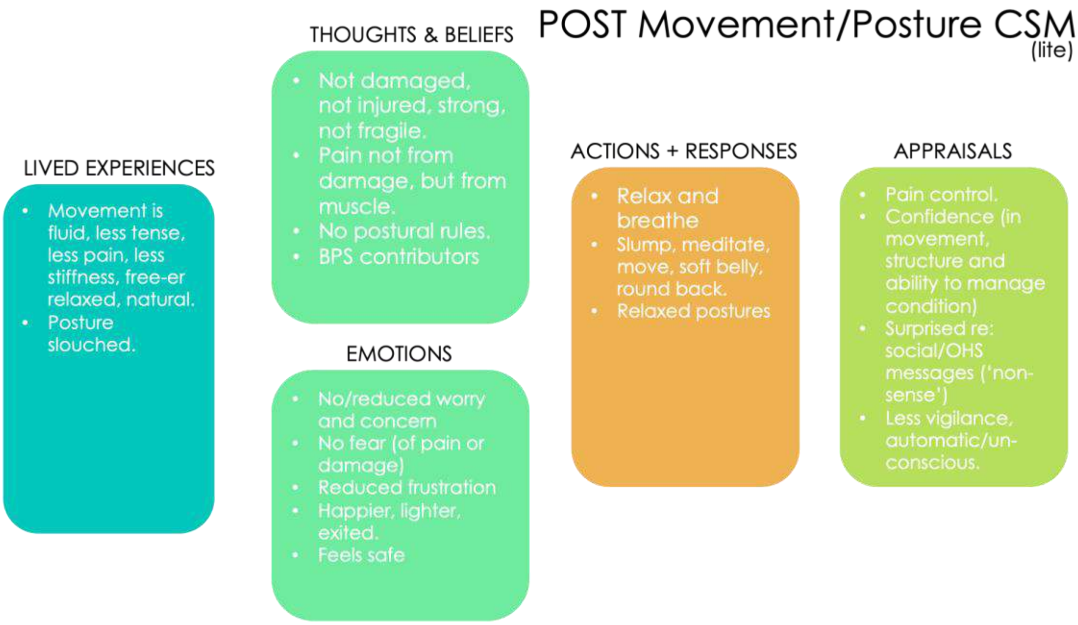
Perhaps this reflects that this is too much of a 'deeper code' (about the reflections of the people with LBP). Perhaps the codes that may fit here are already captured by the 'lived experience' code??

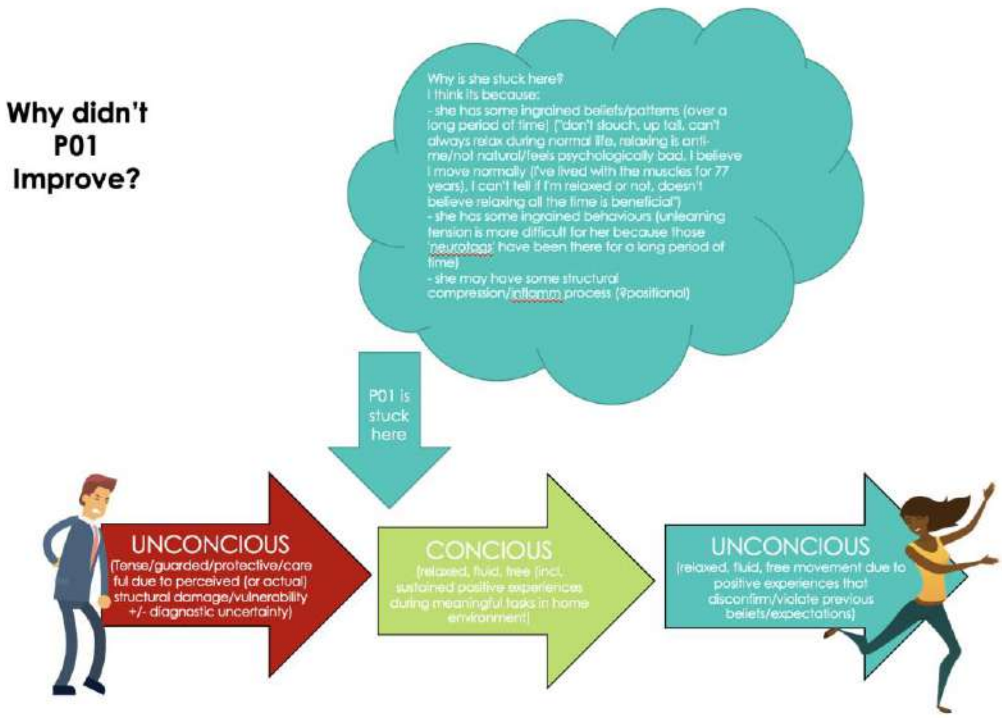
Kevin Werali
I also see these two broad themes as both originating from 'conflicting experiences' and therefore could be condensed into a single theme?

Kevin Werali
This was a first order code, I didn't code anything with this yet so would be fine to delete ☺

Development of early figures






Why didn't P01 Improve?
Why is she stuck here?
I think its because:
- she has some ingrained beliefs/patterns (over a long period of time) ("don't slouch, up tall, can't always relax during normal life, relaxing is anti-me/not natural/feels psychologically bad. I believe I move normally (I've lived with the muscles for 77 years). I can't tell if I'm relaxed or not, doesn't believe relaxing all the time is beneficial")
- she has some ingrained behaviours (unlearning tension is more difficult for her because those 'neurotags' have been there for a long period of time)
- she may have some structural compression/inflamm process (?positional)
P01 is stuck here
UNCONCIOUS
(Tense/guarded/protective/careful due to perceived (or actual) structural damage/vulnerability +/- diagnostic uncertainty)
CONCIOUS
(relaxed, fluid, free (incl. sustained positive experiences during meaningful tasks in home environment)
UNCONCIOUS
(relaxed, fluid, free movement due to positive experiences that disconfirm/violate previous beliefs/expectations)

F.7 Group membership at follow-up based on qualitative interview

Participant	Kevs Classification (0=non-responder, 1=half responder (conscious non-protect), 2=full responder (unconscious non-protect)	notes after reviewing quali
1	0	
2	2	(float bw 1-2)
3	1	definitely 1
4	2	definitely 2
5	1	definitely 1
6	2	Float bw 1-2, more a 2
7	1	P7: "not automatic yet"
8	2	p8:"now its automatic
9	1	P9:"I need to get into habit of relaxing"
10	2	Mixed, walking automatic, standing not quite - still lots of uncertainty
11	2	Mixed, more a 2: P11:'not thinking about pain as much'
12	2	definitely a 2 P12: "it's relaxing straight away, automatically, without me having to do the exercise to make it, I

F.8 COREQ-32 checklist

COREQ (COnsolidated criteria for REporting Qualitative research) Checklist

A checklist of items that should be included in reports of qualitative research. You must report the page number in your manuscript where you consider each of the items listed in this checklist. If you have not included this information, either revise your manuscript accordingly before submitting or note N/A.

Topic	Item No.	Guide Questions/Description	Reported on Page No.
Domain 1: Research team and reflexivity			
Personal characteristics			
Interviewer/facilitator	1	Which author/s conducted the interview or focus group?	8
Credentials	2	What were the researcher's credentials? E.g. PhD, MD	8
Occupation	3	What was their occupation at the time of the study?	8
Gender	4	Was the researcher male or female?	8
Experience and training	5	What experience or training did the researcher have?	8,9
Relationship with participants			
Relationship established	6	Was a relationship established prior to study commencement?	8
Participant knowledge of the interviewer	7	What did the participants know about the researcher? e.g. personal goals, reasons for doing the research	8
Interviewer characteristics	8	What characteristics were reported about the inter viewer/facilitator? e.g. Bias, assumptions, reasons and interests in the research topic	8
Domain 2: Study design			
Theoretical framework			
Methodological orientation and Theory	9	What methodological orientation was stated to underpin the study? e.g. grounded theory, discourse analysis, ethnography, phenomenology, content analysis	9-11
Participant selection			
Sampling	10	How were participants selected? e.g. purposive, convenience, consecutive, snowball	6
Method of approach	11	How were participants approached? e.g. face-to-face, telephone, mail, email	6
Sample size	12	How many participants were in the study?	6
Non-participation	13	How many people refused to participate or dropped out? Reasons?	13,14
Setting			
Setting of data collection	14	Where was the data collected? e.g. home, clinic, workplace	8
Presence of non-participants	15	Was anyone else present besides the participants and researchers?	8
Description of sample	16	What are the important characteristics of the sample? e.g. demographic data, date	53,61-63
Data collection			
Interview guide	17	Were questions, prompts, guides provided by the authors? Was it pilot tested?	58,8
Repeat interviews	18	Were repeat inter views carried out? If yes, how many?	8,9,56
Audio/visual recording	19	Did the research use audio or visual recording to collect the data?	8
Field notes	20	Were field notes made during and/or after the inter view or focus group?	9
Duration	21	What was the duration of the inter views or focus group?	14
Data saturation	22	Was data saturation discussed?	11,36,36
Transcripts returned	23	Were transcripts returned to participants for comment and/or	9

Topic	Item No.	Guide Questions/Description	Reported on Page No.
		correction?	
Domain 3: analysis and findings			
Data analysis			
Number of data coders	24	How many data coders coded the data?	10-11
Description of the coding tree	25	Did authors provide a description of the coding tree?	9-10
Derivation of themes	26	Were themes identified in advance or derived from the data?	11
Software	27	What software, if applicable, was used to manage the data?	9
Participant checking	28	Did participants provide feedback on the findings?	9
Reporting			
Quotations presented	29	Were participant quotations presented to illustrate the themes/findings? Was each quotation identified? e.g. participant number	14-30, 57, 72-76
Data and findings consistent	30	Was there consistency between the data presented and the findings?	14-30
Clarity of major themes	31	Were major themes clearly presented in the findings?	14-30
Clarity of minor themes	32	Is there a description of diverse cases or discussion of minor themes?	14-30

Developed from: Tong A, Sainsbury P, Craig J. Consolidated criteria for reporting qualitative research (COREQ): a 32-item checklist for interviews and focus groups. *International Journal for Quality in Health Care*. 2007. Volume 19, Number 6: pp. 349 – 357

Once you have completed this checklist, please save a copy and upload it as part of your submission. DO NOT include this checklist as part of the main manuscript document. It must be uploaded as a separate file.