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The Effect of Dynamic Sitting on Trunk Muscle Activation: A Systematic Review

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ABSTRACT:

The purpose of this systematic review was to investigate the effect of dynamic sitting on trunk muscle activation in sitting. Electronic databases were searched by two independent reviewers. Studies were included if they compared the effect of dynamic sitting on trunk muscle activation to a more static sitting condition. Seven studies were eligible for inclusion, six of which were rated as "high-quality" using the PEDro scale. Five studies reported no difference in trunk muscle activation. Two studies reported a difference in trunk muscle activation, yet this was associated with increased discomfort, increased fatigue and greater spinal shrinkage. Furthermore, the changes reported in these two studies may be more related to the absence of a backrest rather than dynamic sitting. Therefore, the findings of this review suggest dynamic sitting does not significantly change trunk muscle activation. No randomised clinical trials or longitudinal design studies were found which evaluated the effect of dynamic sitting on trunk muscle activation, limiting the ability to make definitive conclusions about causality. The implications of the results, and recommendations for future research, are discussed.

Keywords: dynamic sitting; back pain; muscle.

1. Introduction

1.1 Sitting and low back pain

The incidence of, and costs associated with, low back pain (LBP) remain very high (Lloyd et al., 1986; Woolf and Pfleger, 2003). A large number of people with LBP report that their symptoms are aggravated during sitting (Womersley and May, 2006). Since sitting duration alone does not seem to be linked to the onset of LBP (Bakker et al., 2007; Lis et al., 2007; Roffey et al., 2010b), other aspects of sitting are worthy of consideration in the management of LBP. For example, different seating options such as the use of a backrest (Vergara and Page, 2000), adjustable height seats (Koskelo et al., 2007) or chairs/devices which increase lumbar lordosis (Gadge and Innes, 2007; McGill and Fenwick, 2009) may help reduce LBP.

1.2 How could dynamic sitting help?

Recent research suggests that subjects with LBP assume more static, sustained end-range postures while sitting, and use large infrequent shifts in posture rather than small, subtle spinal movements regularly (Dankaerts et al., 2006; Telfer et al., 2009; Vergara and Page, 2002). As a result, dynamic sitting approaches which facilitate subtle spinal motion have been proposed as a means of reducing LBP during sitting (Van Dieen et al., 2001). While most sitting involves some degree of movement, “dynamic sitting” as referred to in this review relates to the increased motion in sitting which is facilitated by the use of specific chairs or equipment.

There is considerable evidence of deficits in trunk muscle activation patterns in people with LBP (MacDonald et al., 2009; Tsao et al., 2010). There is also evidence that altered patterns of trunk muscle activation among subjects with LBP are linked to their seated posture

(Dankaerts et al., 2009). As a result, methods of facilitating spinal motion and varying trunk muscle activation in sitting have gained popularity. These dynamic sitting approaches include the use of chairs and stools with a degree of motion, exercise balls, and passive motion devices on seats, with a view to the dynamic nature of sitting facilitating spinal motion (McGill and Fenwick, 2009; McGill et al., 2006; Van Deursen et al., 2000; Van Dieen et al., 2001). It has been proposed that the use of these dynamic sitting approaches may vary trunk muscle activation, and thereby alter the loading of spinal structures (McGill and Fenwick, 2009; Van Dieen et al., 2001). However, there is a vast range of dynamic sitting options available, and it is not clear if any of these approaches significantly modify trunk muscle activation during sitting.

1.3 Aim

The aim of this systematic review was to investigate the effect of dynamic sitting on trunk muscle activation during sitting when compared to a more static sitting condition.

2. Methods

2.1 Overview

The Cochrane and MEDLINE databases were initially searched, revealing no systematic reviews about the effectiveness of dynamic sitting on trunk muscle activation. Studies were included in this review if they compared the effect of a dynamic sitting condition on trunk muscle activation to at least one other more static sitting condition. The review was registered on the PROSPERO database (CRD42011001714) (PROSPERO, 2011), and has been reported in accordance with the PRISMA statement (Moher et al., 2009).

2.2 Search strategy and inclusion criteria

The following databases were searched during July 2011; MEDLINE, SPORTdiscus, CINAHL, AMED, Academic Search Complete, Embase and Web of Science. Two assessors (KOS, MOK) independently searched these databases using an agreed range of keywords. The search strategy used four groups of keywords, similar to previous research (Rivilis et al., 2008). These groups of keywords related to either (1) a dynamic sitting intervention, (2) the low back region, (3) muscle activation, or (4) sitting. The specific keywords for each group were; (1) "stable OR unstable OR stability OR instability OR dynamic OR passive motion", (2) "lumbar OR low back OR back", (3) "muscle OR activ*" and (4) "sitting OR sit OR seat OR stool OR chair OR ball". The groups of keywords were then combined using 'AND' (Figure 1). To be considered for this review, the title and abstract had to contain at least one keyword from each group. Studies were limited to those involving humans, published in English, after 1990. Only peer-reviewed articles were considered. Conference proceedings were excluded because they are not consistently peer reviewed, and often lack sufficient information to adequately assess methodological quality. After the removal of duplicates, the titles and abstracts of the articles which met these criteria were then screened for suitability. If no abstract was available, or when it was not clear if the study should be included, full text articles were retrieved in order to determine inclusion or exclusion.

Studies were included if they compared dynamic sitting to at least one other more static sitting condition, and measured the activation of at least one trunk muscle in either painfree subjects, or among people with LBP. No minimum follow-up period was required, such that single-session comparisons of dynamic sitting to another sitting condition were eligible. Studies were excluded if they solely examined the effects of dynamic sitting on other parameters such as discomfort, posture, postural sway or spinal shrinkage. Studies were excluded if they involved seats or chairs which cannot be used in typical daily environments such as the office, car and home (Wilder et al., 1994). Finally, studies were also excluded if they did not involve a more static comparison (Callaghan and McGill, 2001; Reeves et al., 2006). The reference lists of the selected articles were also manually searched for any further relevant articles, but no additional studies were found.

2.3 Assessment of methodological quality

Methodological quality was rated independently by two assessors (KOS, MOK) using the PEDro scale. The PEDro score is a reliable (Maher et al., 2003) and valid (de Morton, 2009) method of assessing trial quality. The purpose of the PEDro scale is to evaluate the internal validity of a study, and how interpretable the study results are. There are 11 criteria, 10 of which are scored. When it was unclear whether a study did or did not meet one of the PEDro criteria, the author of the original study was contacted for clarity. Regarding the “baseline comparability” criterion, a study must typically describe at least one measure of the severity of the disorder being studied for the score to be awarded on the PEDro scale. While this cannot be applied in studies of painfree participants, in crossover design studies both groups are obviously the same. Therefore, points for this criterion were awarded for crossover design studies, despite there being no measure of “severity” available. In the event of disagreement between the two raters for an individual study, a consensus decision was reached. The quality was classified as ‘high’ (>6/10), ‘fair’ (≥4/10), or ‘poor’ (<4/10), according to PEDro scores (Ye et al., 2011), to aid interpretation of study quality in the event of inconsistent findings. In addition, the overall quality of the studies was evaluated under the headings of bias, confounding factors, strength of the results and clinical applicability. This was done by two authors independently evaluating these headings and reaching a consensus decision for each of these headings.

2.4 Data extraction and synthesis

For each study, the following data were extracted by two assessors (KOS, MOK) and cross-checked for accuracy; (1) sample size (2) participant gender, (3) participant age, (4) study design, (5) dynamic and control sitting interventions, (6) task performed and task standardisation, (7) muscle group studied, (8) how muscle activation was analysed, (9) inclusion/exclusion criteria, and (10) the main results. Significant differences in the muscles studied, the type of muscle activity examined, the dynamic sitting intervention used, and the comparison sitting condition did not allow for pooled analysis of the data.

3. Results

3.1 Identification of studies

The method by which studies were included and excluded is outlined in Figure 2. The electronic search resulted in a total of 778 potentially relevant papers, which was reduced to 573 after the removal of duplicates. After screening of the title and abstract of each article, nine articles were identified as being potentially relevant. After reviewing these full-text articles, seven articles met the inclusion and exclusion criteria, with the other two articles being excluded at this stage due to not including a “more static” sitting condition (Callaghan and McGill, 2001; Reeves et al., 2006). Searching the reference lists of these articles did not add any further articles. Therefore, the final number of articles included in this review was seven (Beach et al., 2003; Ellegast et al., 2012; Gregory et al., 2006; Kingma and van Dieen, 2009; McGill et al., 2006; O'Sullivan et al., 2006; Van Dieen et al., 2001). All seven were crossover design studies of painfree participants. The main details of each study are provided in Table 1.

3.2 Critical Appraisal

As evident in Table 2, six of the seven studies included in this review were rated as “high” quality (>6/10) using the PEDro scale, with one study (Kingma and van Dieen, 2009) rated as “fair” quality. The highest score obtained by any study was 8/10 (Beach et al., 2003; Ellegast et al., 2012).

3.2.1 Bias

The randomisation and concealment procedures used were satisfactory in six studies. One study (Kingma and van Dieen, 2009) instead allocated participants in a pre-determined order, although in a repeated measures design this may not be a major concern. Since all seven studies were crossover studies, participants were obviously no different at baseline between the groups. The assessor was only blinded to the sitting condition in one study (Beach et al., 2003). Similarly, only one study (Ellegast et al., 2012) blinded participants to the sitting conditions. No study included blinded investigators, which is difficult to envisage in such trials. Although providing detail about inclusion and exclusion criteria reduces selection bias, all studies included painfree participants with minimal additional details provided. Two studies (Kingma and van Dieen, 2009; McGill et al., 2006) did not include both male and female participants. There were no dropouts in any study, eliminating the risk of attrition bias affecting the results.

3.2.2 Confounders

The type of chair used to deliver the dynamic sitting component varied between studies. Three studies (Gregory et al., 2006; Kingma and van Dieen, 2009; McGill et al., 2006) used an exercise ball with no backrest. One study (O'Sullivan et al., 2006) used an air-filled cushion positioned on a backless stool. One study (Beach et al., 2003) used a continuous passive motion (CPM) device on a chair with a backrest to intermittently modify lumbar curvature. One study (Ellegast et al., 2012) used four different dynamic chairs, all with backrests, which allowed various directions and degrees of movement in sitting. Another study (Van Dieen et al., 2001) used two variations of a chair with moveable parts including a backrest. As a result, only three studies (Beach et al., 2003; Ellegast et al., 2012; Van Dieen et al., 2001), assessed "supported" dynamic sitting i.e. sitting with a backrest. An even greater potential confounder is that the presence of a backrest, which is known to influence trunk muscle activation and discomfort (Andersson et al., 1974; Vergara and Page, 2002), was not consistent between the dynamic and more static condition in two studies (Gregory et al., 2006; Kingma and van Dieen, 2009).

The type of task performed varied between studies. Five studies (Beach et al., 2003; Ellegast et al., 2012; Gregory et al., 2006; Kingma and van Dieen, 2009; Van Dieen et al., 2001) had participants performing office tasks during testing. The type of office tasks performed differed between these studies. In one study (Kingma and van Dieen, 2009), participants performed a single typing task, while in another study (Beach et al., 2003), participants were permitted to perform any computer task which required using the mouse and keyboard. Other studies instructed participants to perform either three (Van Dieen et al., 2001), four (Gregory et al., 2006) or seven (Ellegast et al., 2012) different office tasks. On the other hand, participants watched a movie in the two remaining studies (McGill et al., 2006; O'Sullivan et al., 2006). Given that the performance of different tasks causes significant variations in participant postures and movements (Groenesteijn et al., 2012), the variation of tasks performed in these studies complicates interpretation of the different studies. However, as long as the tasks performed for each of the sitting conditions were the same within each study, this is not a major concern. In one study (Beach et al., 2003), the tasks were not standardised across all participants, which could confound their results.

The testing procedures varied between trials. Only two studies (Beach et al., 2003; Ellegast et al., 2012) did not perform chair adjustments or standardisation of hip and knee angles prior to testing. However in one of these studies (Beach et al., 2003), the height and inclination of the backrest were instead adapted to the individual subject, which enhances clinical applicability but could lead to discrepancies. All other studies ensured similar lower limb alignment between sitting conditions through minor adjustments of the setup as required, although one study (McGill et al., 2006) used a non-adjustable stool as the comparison condition for all participants.

Only two studies (Ellegast et al., 2012; Kingma and van Dieen, 2009), mentioned allowing participants to become accustomed to the dynamic sitting exposure. One study (Kingma and van Dieen, 2009) allowed participants sit on the exercise ball while doing computer work for one hour on two occasions during the previous week, while in the other study (Ellegast et al., 2012), all participants spent several days testing each chair type in the course of their normal office work before beginning testing. All studies involved relatively short durations of sitting. Sitting duration varied between five minutes (O'Sullivan et al., 2006), thirty minutes (McGill et al., 2006), one hour (Beach et al., 2003; Gregory et al., 2006; Kingma and van Dieen, 2009), 100 minutes (Ellegast et al., 2012) and three hours (Van Dieen et al., 2001). Notwithstanding these variations, the duration of sitting was similar between the dynamic and more static sitting conditions in each study.

To minimise the potential effect of fatigue, three studies (Ellegast et al., 2012; Kingma and van Dieen, 2009; Van Dieen et al., 2001) examined the sitting exposures on separate days. In one of these studies (Ellegast et al., 2012), three chairs were tested on one day and two chairs on the next day, with a one hour break provided between each. While this reduces the risk of fatigue contaminating the results, there is evidence of greater variation in muscle activation expressed relative to maximum voluntary contraction (%MVC) or sub-maximum voluntary contraction (%sub-MVC) when tested on different days (Dankaerts et al., 2004). Two other studies (McGill et al., 2006; O'Sullivan et al., 2006) simply provided a 10 minute rest period between sitting conditions on the same day. In contrast, two studies (Beach et al., 2003; Gregory et al., 2006) did not report any rest period.

3.2.3 Strength of Results

All seven studies used a crossover design, which is appropriate for the research question. No randomised controlled trials (RCT) or longitudinal design studies were found. All studies used appropriate methods of statistical analysis, thus increasing the strength of the results obtained. All studies included relatively small samples, ranging from eight (Beach et al., 2003; McGill et al., 2006) to 26 (O'Sullivan et al., 2006). None of the studies calculated their sample size based on a power calculation. As a result, the studies may have been underpowered to detect differences in trunk muscle activation between sitting conditions.

The trunk muscles analysed varied between studies. Six studies analysed at least two paraspinal muscles, while one study (Ellegast et al., 2012) analysed one paraspinal muscle. Three studies (Gregory et al., 2006; McGill et al., 2006; O'Sullivan et al., 2006) analysed some of the abdominal muscles, two studies analysed trapezius (Ellegast et al., 2012; Kingma and van Dieen, 2009), and one study analysed latissimus dorsi (McGill et al., 2006). However, even those who studied similar muscles did not always analyse the same portions of a muscle or use the same electrode placements (Ellegast et al., 2012; Gregory et al., 2006; Kingma and van Dieen, 2009). A further complication is that trunk muscle activation was not always the primary outcome measure in these studies, such that detailed data including points estimates and variability were not provided in one study (Van Dieen et al., 2001). All muscles were analysed bilaterally, with one study (Kingma and van Dieen, 2009) averaging data from each side rather than analysing each side separately to investigate side:side differences.

The primary measure of trunk muscle activation used was average amplitude of activation which was provided in all studies, either relative to %MVC (Beach et al., 2003;

Gregory et al., 2006; Kingma and van Dieen, 2009; McGill et al., 2006; Van Dieen et al., 2001) or %sub-MVC (Ellegast et al., 2012; O'Sullivan et al., 2006). In two cases (Ellegast et al., 2012; Van Dieen et al., 2001), the average measure used was median amplitude rather than mean activation. The second most common type of comparison between the sitting conditions was examination of muscle rest periods, which was done in four studies (Beach et al., 2003; Gregory et al., 2006; Kingma and van Dieen, 2009; Van Dieen et al., 2001). Three of these four studies (Beach et al., 2003; Gregory et al., 2006; Van Dieen et al., 2001) compared the proportion of time spent at rest between the sitting conditions using an amplitude probability distribution function (APDF), although the percentage of muscle activation which was considered at rest varied slightly. The other study to consider rest examined the amplitude of activation in the lowest 5% of activation, again using an APDF (Kingma and van Dieen, 2009). Some studies also examined the number (Beach et al., 2003; Gregory et al., 2006) and duration (Gregory et al., 2006) of muscle rest periods in each sitting condition. A third muscle activation parameter considered by two studies was the variation in activation, either as the degree of variation in activation (O'Sullivan et al., 2006) or the rate of change in amplitude (Kingma and van Dieen, 2009). Finally, measures of spinal stability or cocontraction were compared in two studies (Gregory et al., 2006; McGill et al., 2006) while fatigue, using analysis of the mean power frequency (MPF), was compared in one study (Kingma and van Dieen, 2009).

3.2.4 Clinical Applicability

No study included participants with LBP, limiting the external validity and generalisability of the studies. As stated previously, five studies (Beach et al., 2003; Ellegast et al., 2012; Gregory et al., 2006; Kingma and van Dieen, 2009; Van Dieen et al., 2001) had participants performing office tasks during testing, with participants watching a movie during testing in the other two studies (McGill et al., 2006; O'Sullivan et al., 2006). While simulating occupational tasks increases the clinical applicability and ecological validity of the results, one study (Beach et al., 2003) did not standardise the task across all subjects, which could confound their results (Groenesteijn et al., 2012).

3.3 Description of Results

Three studies (Gregory et al., 2006; Kingma and van Dieen, 2009; McGill et al., 2006) investigated the use of an exercise ball, while another study (O'Sullivan et al., 2006) investigated a very similar inflatable cushion placed on a stool. Using an inflatable cushion made no significant difference to any muscle activation parameters in three trunk muscles (lumbar multifidus (LM), lumbar erector spinae (LES) and internal oblique (IO)) among 26 painfree participants (O'Sullivan et al., 2006). Using a similar approach with an exercise ball, another study (McGill et al., 2006) recorded no significant difference in the mean activation of six trunk muscles (rectus abdominus (RA), IO, external oblique (EO), latissimus dorsi (LD), thoracic erector spinae (TES), and LES) among eight painfree participants. A study (Gregory et al., 2006) comparing sitting for one hour on an exercise ball to an office chair among 14 painfree participants also observed no significant difference in the mean activation of three (LES, RA, EO) of the four trunk muscles studied. However, the activation of one trunk muscle (TES) was increased on the stability ball, albeit only on one side. Interestingly, this study also analysed the degree of discomfort in each sitting condition, and low back discomfort (LBD) was significantly greater for the dynamic sitting (exercise ball) condition. Finally, sitting on an exercise ball was associated (Kingma and van Dieen, 2009) with higher mean activation, greater activation during rest periods, greater variation in activation and greater LES muscle fatigue in 10 painfree participants. These parameters were all significantly different for LES, but not for TES or trapezius. Interestingly, while discomfort was not formally evaluated, they reported increased LBD and upper back discomfort on the exercise ball, similar to Gregory et al. 2006.

One study (Beach et al., 2003) investigated the effect of a CPM device (“Backcycler”) on trunk muscle activation (LES and TES) among eight painfree participants during one-hour of computer work sitting on a chair with a backrest. There were no significant differences in any trunk muscle activation parameters, or back discomfort, between the two sitting conditions.

One study (Van Dieen et al., 2001) compared sitting on two types of dynamic chair to sitting on a more static office chair. The two dynamic chairs varied by one of them having a seat and backrest moveable in a fixed ratio to one another, and another having a freely movable seat and backrest. The three sitting trials were performed on three different days, with 10 painfree participants sitting on a different chair each day. There were no significant differences in any trunk muscle activation parameters (LES and TES) or overall body discomfort between the sitting conditions. Spinal shrinkage was however reduced after dynamic sitting, in contrast to another study of dynamic sitting in this review (Kingma and van Dieen, 2009).

Finally, another study (Ellegast et al., 2012) compared sitting on four specific dynamic chairs to sitting on a more static office chair. The difference between the four specific dynamic chairs and the more static chair which was used as a control was that the specific dynamic chairs allowed varying 3D movements of the seatpan, while the more static chair allowed only 2D movements of the seatpan. The five sitting trials were performed over two days, with ten painfree participants sitting for 100 minutes on three different chairs on the first day and on two other chairs on the second day. There were no significant differences in muscle activation (trapezius and LES) between the sitting conditions.

4. Discussion

This systematic review identified no RCT or longitudinal design studies which evaluated the effect of dynamic sitting on trunk muscle activation, limiting the ability to make definitive conclusions about causality. Seven studies were found which investigated the effect of a dynamic sitting intervention on trunk muscle activation. Five studies reported no significant differences when sitting on a dynamic sitting device. In the two studies (Gregory et al., 2006; Kingma and van Dieen, 2009) which reported at least some changes in trunk muscle activation, the dynamic sitting condition was associated with disadvantages such as increased LBD (Gregory et al., 2006; Kingma and van Dieen, 2009), greater spinal shrinkage (Kingma and van Dieen, 2009) and greater fatigue (Kingma and van Dieen, 2009). As a result, this systematic review does not support the use of dynamic sitting approaches as an effective, or beneficial, means of modifying trunk muscle activation during sitting.

4.1 Interpretation of Results

Both of the studies (Gregory et al., 2006; Kingma and van Dieen, 2009) which demonstrated differences in trunk muscle activation involved unsupported sitting on an exercise ball (Gregory et al., 2006; Kingma and van Dieen, 2009). However, the other two unsupported dynamic sitting studies (McGill et al., 2006; O'Sullivan et al., 2006) reported no differences in trunk muscle activation. It could be suggested that this is related to these two studies (McGill et al., 2006; O'Sullivan et al., 2006) involving the shortest durations of sitting exposure (5 and 30 mins) and one of them having a very small sample size (n=8) (McGill et al., 2006), such that differences may have been evident if larger groups of people were sitting for longer. However, the two studies (Gregory et al., 2006; Kingma and van Dieen, 2009) which reported a significant difference also used small samples (n=10 and n=14). Instead, the comparison sitting condition used is likely to be a more important factor. The two studies (Gregory et al., 2006; Kingma and van Dieen, 2009) which reported significantly higher muscle activation during unsupported dynamic sitting used a chair with a backrest as their sitting comparison. On the other hand, the two studies (McGill et al., 2006; O'Sullivan et al., 2006) which reported no difference in muscle activation during unsupported dynamic sitting used an unsupported sitting comparison. In other words, the differences reported with dynamic sitting may simply relate to the presence of a backrest in the comparison sitting condition (Gregory et al., 2006; Kingma and van Dieen, 2009). Consistent with this, neither of the three supported dynamic sitting approaches (Beach et al., 2003; Ellegast et al., 2012; Van Dieen et al., 2001) demonstrated any change in trunk muscle activation with dynamic sitting. This is also consistent with data demonstrating that use of a backrest can reduce trunk muscle activation (Andersson et al., 1974). Regardless of the use of a backrest, none of the three studies which evaluated the abdominal muscles reported any changes at all with dynamic sitting.

The suggestion that the differences between studies are, at least partly, explained by the presence or absence of a backrest is also supported by data on discomfort in these studies. Three of the studies included in this review formally compared the level of discomfort between sitting conditions. The only one of these three studies to report increased discomfort (Gregory et al., 2006) was the only one examining unsupported dynamic sitting. Considering the fact that this study (Gregory et al., 2006) and the only other study (Kingma and van Dieen, 2009) reporting increased trunk muscle activation, both reported increased discomfort, suggests that sustained paraspinal muscle activation during unsupported dynamic sitting may be closely linked to the development of discomfort. In at least one of the studies (Gregory et al., 2006), this increased muscle activation and increased discomfort was probably related to greater anterior pelvic tilt during dynamic sitting.

In a similar manner, the contrasting findings regarding spinal shrinkage in these studies is helpful in interpreting the results of this review. Two studies (Kingma and van Dieen, 2009; Van Dieen et al., 2001) examined the effect of dynamic sitting on spinal shrinkage. In these studies, spinal shrinkage was reduced after supported dynamic sitting (Van Dieen et al., 2001) and increased after unsupported dynamic sitting (Kingma and van Dieen, 2009). Furthermore, the mean paraspinal muscle activation levels reported were much higher in the study which reported greater spinal shrinkage (Kingma and van Dieen, 2009).

Therefore, the results suggest that dynamic sitting itself has little effect on trunk muscle activation. The level of trunk muscle activation during unsupported dynamic sitting is greater than during supported static sitting, but no different to that observed during unsupported static sitting. Therefore, the use of a backrest appears to have a greater influence on trunk muscle activation than whether the sitting condition used is static or dynamic. It is not clear what constitutes an appropriate level of trunk muscle activation during sitting, with varying suggestions on what constitutes ideal lumbar posture and muscle activation (Claus et al., 2009; O'Sullivan et al., 2012a; O'Sullivan et al., 2012b; O'Sullivan, 2012; Pynt et al., 2001). However, even a small increase in muscle activation can lead to fatigue (van Dieën et al., 2009). As a result, it is important that changes in trunk muscle activation, if they are to be seen as advantageous, are linked to changes in clinically relevant outcomes.

4.2 Effect of Dynamic Sitting on other Parameters

The lack of effectiveness of dynamic sitting on trunk muscle activation is consistent with data on other parameters examined in dynamic sitting. For example, there is limited or conflicting evidence that dynamic sitting is associated with changes in lumbar posture (Gregory et al., 2006; McGill et al., 2006; O'Sullivan et al., 2006; Van Dieen et al., 2001). However, even if dynamic sitting did increase seated spinal motion (Kingma and van Dieen, 2009; O'Sullivan et al., 2006), and facilitate greater variation in muscle activation (Kingma and van Dieen, 2009) without the cost of higher mean activation and fatigue (Kingma and van Dieen, 2009), these changes need to be linked with improvements in clinically relevant outcomes.

Instead, the results from the small number of studies which have examined the effect of dynamic sitting on LBP have been contradictory (Aota et al., 2007; Lengsfeld et al., 2007; Reinecke et al., 1994; van Deursen et al., 1999). Once again, variations in the dynamic sitting device used, and the comparison sitting condition used, partially explain these contradictions.

4.3 Relevance to LBP

No studies in this review included subjects with LBP, which greatly limits the clinical relevance of the findings. The findings in subjects without LBP cast doubt on whether dynamic sitting would effectively alter trunk muscle activation among LBP patients. The lack of evidence to support dynamic sitting as an effective intervention for LBP, or to facilitate specific trunk muscle activation, is consistent with LBP being a multi-dimensional disorder which encompasses biological, psychosocial, genetic and environmental factors (O'Sullivan, 2012) rather than simply spinal loading (Roffey et al., 2010a; Roffey et al., 2010c) or spinal pathology (Jarvik et al., 2001; Savage et al., 1997). Therefore, while prolonged sitting is a common aggravating factor for people with LBP (Dankaerts et al., 2006; Williams et al., 1991), and differences in sitting posture may be present among people with LBP (Dankaerts et al., 2006), there is no evidence that sitting duration, statically or dynamically, is a significant risk factor for the development of LBP (Roffey et al., 2010b).

4.4 Recommendations

Future studies should address some of the limitations of the studies included in this review. Studies with larger sample sizes, involving longer durations of sitting are required. There is a clear need for studies involving participants with LBP, to enhance the clinical relevance of these studies. Ideally this would involve participants with LBP who report specific aggravation of their symptoms in sitting, and who are trained appropriately on the use of their dynamic sitting device. This may require consideration of specific subgroups of LBP patients (Dankaerts et al., 2009). Standardisation of participant tasks should be ensured as variation in these affects trunk muscle activation (Ellegast et al., 2012; Groenesteijn et al., 2012; Van Dieen et al., 2001). This should include consideration of limb dominance, as this could have contributed to the differences observed in one of the included studies (Gregory et al., 2006). Greater detail could be provided on potential confounders, for example the breaks given between sitting conditions and participants becoming accustomed to the dynamic sitting condition. Differentiating the relative contribution of different components of dynamic seats may be useful. For example, the use of backrests (Andersson et al., 1974) or other lumbar supports should be consistent between the sitting comparisons, to help control potential confounding factors, as highlighted earlier in this review. Further, the type of dynamic sitting devices used varied considerably in their action, and differentiating the relative contributions of these components may be worthwhile. A range of muscle activation parameters could be analysed, including mean activation and variation in activation, as well as some measure of sitting discomfort. The use of dynamic sitting approaches with LBP patients as one component of a comprehensive biopsychosocial management programme requires further study.

4.5 Limitations

The main limitation of this systematic review is that significant differences in the muscles studied, the type of muscle activity examined, the dynamic sitting intervention used and the comparison sitting condition did not allow for pooled analysis of the data. However, the discussion above outlines how the evidence is relatively consistent once the confounding variables are considered. It is also worth noting that when using the PEDro scale, study authors are typically not contacted for further information about trial methodology. However, the additional information obtained after emailing study authors directly improved the detail provided on the study, and increased their study score in all cases.

5. Conclusions

This systematic review included no RCT or longitudinal design studies which evaluated the effect of dynamic sitting on trunk muscle activation, limiting the ability to make definitive conclusions about causality. Seven studies were found investigating trunk muscle activation during dynamic sitting compared to another sitting condition. Six of the seven studies were rated as high-quality on the PEDro scale. All involved small samples of painfree participants. All seven studies considered the dynamic sitting condition as a stand-alone approach. The results were relatively consistent. Five studies reported no difference in trunk muscle activation. Two studies reported a difference in the activation of some trunk muscles, yet this was associated with increased discomfort, greater fatigue and greater spinal shrinkage. Furthermore, the changes reported in these two studies may be more related to the absence of a backrest rather than the dynamic sitting component. The results suggest that dynamic sitting approaches are ineffective in modifying trunk muscle activation, and that increased trunk muscle activation in sitting is not necessarily associated with better clinical outcomes. Future research should discriminate between supported and unsupported dynamic sitting approaches to address some of the confounding factors identified in this study.

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Disclosure Statement

Four of the authors are currently involved in a study of a novel dynamic sitting device (www.backapp.eu) used in the management of low back pain. That study is part-funded by the manufacturers of the dynamic sitting device. The authors do not feel this has in any way affected this systematic review on dynamic sitting, but are disclosing this fact to enhance transparency. None of the authors have any stake/shares in any form of dynamic sitting device.

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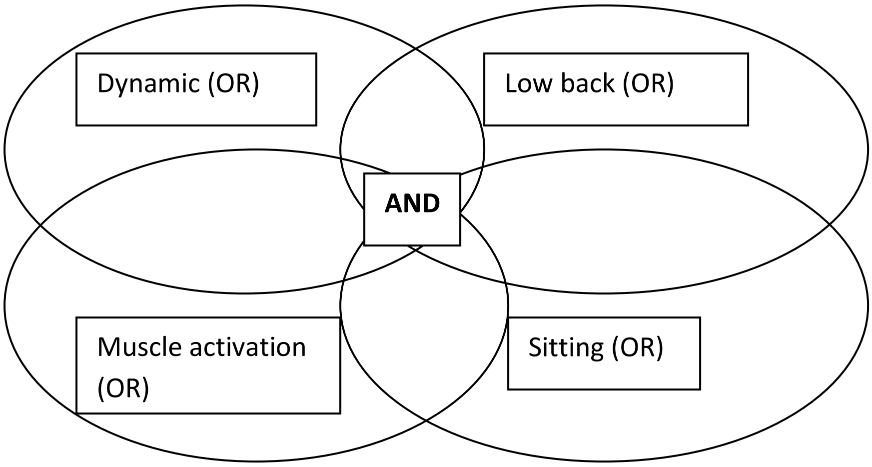
Figure legends:

Figure 1: Boolean logic of the search strategy.

Figure 2. Flow chart of study selection procedure


Dynamic (OR)
Low back (OR)
AND
Muscle activation (OR)
Sitting (OR)

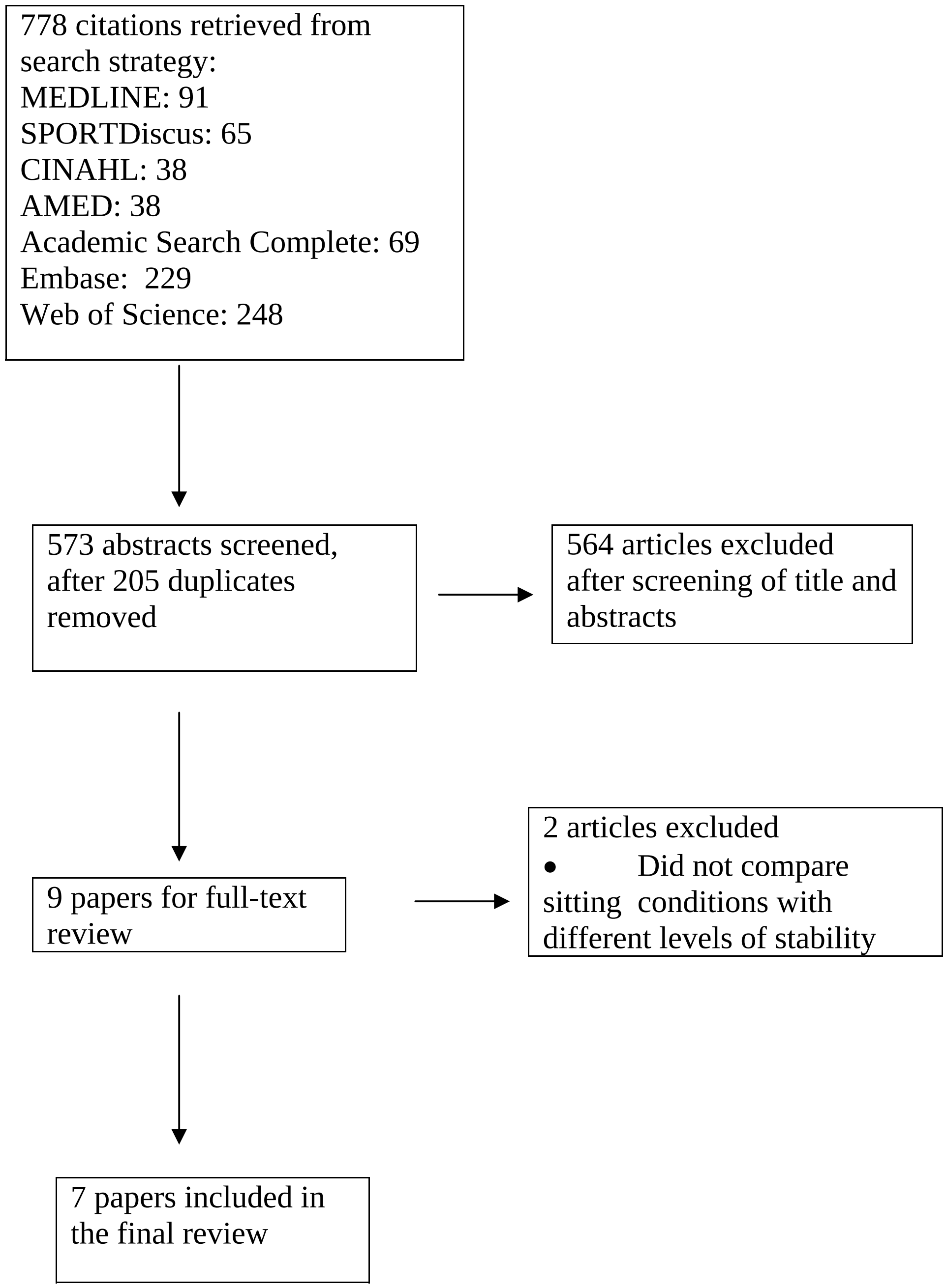

778 citations retrieved from search strategy:
MEDLINE: 91
SPORTDiscus: 65
CINAHL: 38
AMED: 38
Academic Search Complete: 69
Embase: 229
Web of Science: 248
573 abstracts screened, after 205 duplicates removed
564 articles excluded after screening of title and abstracts
9 papers for full-text review
2 articles excluded
• Did not compare sitting conditions with different levels of stability
7 papers included in the final review

Table 1: Description of each study

Study	Sample Size	Gender	Mean Age	Study design	Dynamic sitting intervention	Comparison intervention	Task performed and standardisation	Muscles measured	Muscle activation measure	Inclusion/ Exclusion	Results

										criteria	
Beach et al 2003	8	4M / 4F	23.3	Crossover	Chair with backrest and lumbar support CPM (BackCycler)	Same chair without lumbar support CPM	Computer tasks involving use of mouse and keyboard. Task not standardised, as participants performed their own work.	TES (T9) LES (L3)	Mean activity (%MVC) Rest (APDF0%, number and duration of rest gaps)	No LBP for > 1 year	No sign differen
Ellegast et al 2012	10	5M/5F	35.0	Crossover	Four dynamic chairs with backrests and armrests allowing 3D movements of seatpan	More static chair with backrest and armrests allowing 2D movement of seatpan	Seven office tasks: Reading and correcting text data, typing words, a tracking task with intensive mouse use, reading and correcting text data, typing words, sorting paper files, telephoning. Tasks standardised.	Trapezius LES (L1)	Median activity (50^{th} percentile of sub-MVC) Peak activity (95^{th} percentile of sub-MVC)	Healthy volunteers	No sign differen
Gregory et al 2006	14	7M / 7F	23.85	Crossover	Exercise ball	More static office chair with backrest and without armrests	Four computer tasks: typing, computer-aided design, combined typing and mouse work, and reading. Tasks standardised and in randomised order.	TES (T9) LES (L3) RA EO	Mean activity (%MVC) Rest (APDF0%, number of gaps) Trunk muscle cocontraction	No LBP for > 1 year	Increase TES act exercise No othe differen
Kingma et al 2009	10	0M / 10F	21.7	Crossover	Exercise ball	More static office chair with backrest and armrests	Typing task. Participants typed text from their computer screen in another window, without using the mouse. Task standardised.	TES (T10) LES (L3) Trapezius	Mean activity (%MVC) Rest (APDF5%) Variation in activity (Rate of amplitude change) Fatigue (MPF)	Painfree and working with a computer regularly	Higher activatio activatio greater activatio greater LES on ball. No differen or trape
McGill et al 2006	8	8M / 0F	24.0	Crossover	Exercise ball	Wooden stool without backrest	Watched a movie. Task standardised.	RA IO EO LD TES (T9)	Mean activity (%MVC) Stability and compression index	No LBP history	No sign differen

								LES (L3) LES (L5)			
O'Sullivan et al 2006	26	12M / 14F	31.3	Crossover	Air-filled cushion (SitFit) placed on top of an adjustable stool without a backrest	Same stool without the air-filled cushion	Watched a movie. Task standardised. Computer screen was set at eye level for all participants.	LES (L1) LM (L5) IO	Mean activity (%sub-MVC) Variation in activity (using range of variation)	No LBP or leg pain for > 2 years BMI < 28kg/m^2 No previous postural education	No sign differen
Van Dieen et al 2001	10	7M / 3F	21	Crossover	2 dynamic chairs with backrests and armrests	More static office chair with fixed seat and backrest	3 hour computer task, consisting of computer aided design, word processing and reading a book. Task standardised. Placement of the document was constant for each participant between sitting conditions.	TES (T10) LES (L3)	Median activity (APDF 50%) Rest (APDF 0.5%)	Healthy volunteers	No sign differen

M – male; F – female; CPM – continuous passive motion; TES – thoracic erector spinae; LES – lumbar erector spinae; LM – lumbar multifidus; RA – rectus abdominis; EO – external oblique; IO – internal oblique; LD – latissimus dorsi; T9/T10 – ninth/tenth thoracic vertebra; L1/L3/L5 – first/third/firth lumbar vertebra; APDF 0%/0.5%/5%/50% - amplitude probability distribution function at different percentages; MPF - mean power frequency; LBP - low back pain; BMI – body mass index; %MVC – percentage of maximum voluntary contraction; %sub-MVC - percentage of submaximum voluntary contraction.

Table 2: PEDro score for each study

Study	Random allocation	Concealed allocation	Baseline comparability	Assessors blinded	Participants blinded	Therapists blinded	Follow-up	Intention to-treat analysis	Between group analysis	Points estimates and variability	Total Score / 10
Beach et al 2003	✓	✓	✓	✓	X	X	✓	✓	✓	✓	8
Ellegast et al 2012	✓	✓	✓	X	✓	X	✓	✓	✓	✓	8
Gregory et al 2006	✓	✓	✓	X	X	X	✓	✓	✓	✓	7
Kingma et al 2009	X	X	✓	X	X	X	✓	✓	✓	✓	5
McGill et al 2006	✓	✓	✓	X	X	X	✓	✓	✓	✓	7
O'Sullivan et al 2006	✓	✓	✓	X	X	X	✓	✓	✓	✓	7
Van Dieen et al 2001	✓	✓	✓	X	X	X	✓	✓	✓	X	6