School of Pharmacy and Biomedical Sciences

Self-Care:
Exploring Health Consumers' Interaction with Mobile Health Applications

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Declaration

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.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

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 University Human Research Ethics Committee (EC00262), Approval Number: RDHS-102-15.

Signature:

Date: 25 May 2018

ABSTRACT

Access to technology and health information has been associated with a range of innovations allowing, and encouraging, consumers to participate in self-care using health technologies. Simultaneously, Australia has an ageing population and increasing prevalence of chronic disease, with continual pressure on health care budgets and resources, requiring management of chronic conditions within the community to reduce costs in secondary care. Therefore, deploying innovative techniques to facilitate independent living for patients with chronic diseases is of increasing importance.

This thesis explores how consumers with chronic conditions interact with technology, namely, mobile applications ('apps'), a method for academic evaluation of marketed health apps, and the integration of this method within an ecosystem comprising app developers, consumers and health professionals. While app developers undertake beta-testing and market analysis prior to product launch, little evidence has been published from an independent academic perspective to critique and aim to improve the quality of health apps. The research was conducted in three stages: a qualitative exploration of consumers' use of health apps in general, derivation of a protocol to assess the theoretical usability of health apps, and application of the protocol for asthma and hypertension apps. The research culminated in a translational application of the findings and literature updates presented as a concept map, demonstrating how improved functionality and connectivity can enhance use of consumers' self-monitored health data.

Deductive and inductive thematic analysis produced four dominant themes from the semi-structured interviews of 22 consumers. Thereafter, a 24-question peer-reviewed checklist was created to rate health apps based on criteria derived from literature. A PRISMA-inspired flow diagram shortlisted 14 asthma and 31 hypertension apps, most of which scored considerably below the 80% threshold to identify quality apps. The concept map synthesised findings from all research stages to depict mobile self-care ecosystem processes, including new blockchain technology.

The ever-increasing number of health apps in the Apple and Android marketplace, including decisions around which app is most suitable and effective for a health consumer, creates

challenges for health professionals. Further research into consumers' interaction with health apps will inform health professionals about health consumers' ability to undertake self-care. Using a peer-reviewed usability checklist for health apps, apps can be assessed in terms of their design features and functionality, and endorsed for their appropriateness for a particular population group or health condition.

ABSTRACT (in German)

Diese Doktorarbeit untersucht wie Konsumenten mit chronischen Erkrankungen mit mobiler Technologie interagieren. Diese Methode der Untersuchung wird anhand eines akademischen Messverfahrens, dass zur Bewertung von vermarkteten Gesundheits-Apps benutzt wird, präsentiert. Dieses Messverfahren (Rating) wird in dieser Arbeit in der "Concept-Map/Ecosystem" verwendet. Die Concept-Map/ Ecosystem ist eine Visualisierung von Gesundheits-Apps Geschäftsprozessen, die sich mit App-Entwicklern, Konsumenten und Gesundheitsexperten beschäftigt.

Während App-Entwickler Beta Tests und Marktanalysen verwenden bevor sie das Produkt veröffentlichen, wurden aus unabhängiger akademischer Sicht nur wenige Beweise veröffentlicht, um die Qualität von Gesundheits-Apps zu kritisieren und zu verbessern.

Die Untersuchung der Doktorarbeit wurde in drei Phasen durchgeführt: erstens, eine qualitative Untersuchung der Konsumenten-Verwendung von Gesundheits Apps, zweitens die Ableitung eines Protokolls zur Bewertung der theoretischen Verwendbarkeit von Gesundheits-Apps und drittens, die Anwendung des Protokolls für Asthma- und Hypertonie-Apps.

Diese fachübergreifende Untersuchung beinhaltet Literatur Aktualisierungen und ergab, dass die Concept-Map, mit verbesserter Funktionalität und Konnektivität die Nutzung der selbst überwachenden Gesundheitsdaten der Verbraucher verbessern kann. Die Concept-Map synthetisierte Erkenntnisse aus allen Forschungsphasen, um mobile Self-Care Ecosystem Prozesse, einschließlich neuer Blockchain-Technologie, darzustellen.

Zusammenfassend beschreibt diese Dissertation wie mobile Gesundheitsanwendungen das Alltagsleben von Self-Care Patienten mit chronischen Erkrankungen erleichtern kann.

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Publications arising from this Thesis

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Anderson K, Emmerton LM. The contribution of mobile health applications to self-management by consumers: review of published evidence. *Aust Health Rev*. 2015;40(5).

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Abbreviations

ACDC	App Chronic Disease Checklist
AI	Artificial Intelligence
BCT	Behaviour Change Technique
BLE	Bluetooth low-energy
bpm	beats per minute
ECG	electrocardiogram
FDA	Food and Drug Administration
GP	General Practitioner
HITAM	Health Information Technology Acceptance Model
ICC	Intraclass Correlation Coefficient
ICT	Information and Communication Technology
IT	Information Technology
MARS	Mobile Application Rating Scale
mg/dL	milligrams per decilitre
mmHg	millimetres of mercury
P2P	Peer-to-Peer
PEF	Peak Expiratory Flow
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RCT	randomised controlled trial
TAM	Technology Acceptance Model
TGA	Therapeutic Goods Administration
UK	United Kingdom
USA	United States of America
WA	Western Australia
WHO	World Health Organization
WWW	World Wide Web

1 CHAPTER 1: The Research Problem

1.1 Preface

This chapter provides an introduction to the research problem, its significance and aims, in addition to establishing a body of knowledge to frame the thesis through existing literature and theoretical models. Sections 1.1.1 and 1.1.2 deliver a preface and position to the entire thesis based on the researcher's background.

1.1.1 Organisation of this Dissertation

This thesis contains three papers published by the author, inserted in Chapters 1, 2 and 3, reproduced in accordance with the Creative Commons Attribute 2.0 Generic Licence. The papers have been inserted as images to retain their published format, heading style, spelling and referencing. Tables and figures within the papers therefore retain the numbering used within the paper. Copyright release from each journal is evidenced in appendices. Where required by the journal, co-authors' contributions are specified within the paper.

1.1.2 Background to the Researcher

The PhD candidate (hereafter referred to as the 'researcher') is a practising IT consultant with clinical enterprise systems and app design expertise, aiding in study design, implementation and research participant liaison. The 'client first' consulting ideology facilitated this thesis to encompass an interdisciplinary approach utilising the consumer experience, design science and medical informatics.

During data collection, researcher bias was alleviated by maintaining an objective account of interview proceedings, and employing a certified transcriber to transcribe interview recordings. The transcriptions were then confirmed by the researcher. Respondents were permitted to freely elaborate on their experiences using health apps. Further details of the methodological rigour are provided in the relevant chapter.

The researcher adopted the post-positivist, realism worldview, a scientific methodological approach involving reductionist phenomena.[1] The epistemological assumptions of this research draw upon critical realism.

1.2 Introduction and Background to the Study

With Australia's retirement age and life expectancy increasing, coupled with the existing elderly population, the ability to independently manage one's health is increasingly important.[2] People with chronic medical conditions who have the skills and support to self-manage their health will help relieve pressure on primary care and hospital services. The capability of health consumers to manage their condition in the community environment is referred to as "self-care". This phenomenon is expected to be increasingly important in lives of people with chronic conditions such as sleep apnoea and diabetes.[3] People are becoming more aware of the need for self-care[4] and its short- and long-term benefits.[5]

Self-monitoring is fundamental for self-care of chronic conditions.[6] In order for self-care of a chronic condition to be sustained successfully, self-management techniques need to be integrated into one's life.[7,8] Self-care involves self-monitoring a chronic condition to effectively perform daily decisions.[9] Due to differences between chronic conditions, there is no agreed definition of self-care.[9] Despite being a relatively new phenomenon, self-monitoring has experienced major developments in its practical immersion into one's lifestyle. Self-monitoring is an increasing trend, as evidenced by the international "Quantified Self" movement,[10] and has potential, when undertaken appropriately, to improve healthcare delivery.[11] Initiatives such as the Quantified Self movement encourage self-documentation by health consumers at their individual level of health literacy and Information and Communication Technology (ICT) literacy, commonly using wearable technologies or other monitoring devices.[12]

Boulos et al. (2014) investigated the current health app environment such as quality control and certification for credibility and consumer confidence.[13] This study determined despite the limited availability of app "benchmarking tools," to assess quality and credibility consumers are best equipped through users being educated and consequently increasing health literacy.[13] An important factor when critiquing app quality is to categorise health apps for its intended use. For example, some health apps are created to use as an eBook or for entertainment/prank purposes whilst others are intended for clinical use. However, the authors don't stipulate how many smoking cessation apps are eBooks, entertainment apps or smoking apps without the ability to retain historical readings for clinical management which is what the candidate discovered with asthma and hypertension apps. Additionally, upon reviewing the originally-cited Abroms et al., 2011 article, only 60% of apps were "specific to smoking"; further data on the apps' clinical functionality are not available.[14]

There is a body of literature surrounding self-management by adults with sleep conditions,[15,16] diabetes,[17,18] depression,[19,20] lung cancer,[21,22] chronic back pain,[23,24] chronic obstructive pulmonary disease,[25,26] arthritis,[27,28] stroke[29,30] and osteoporosis.[31,32] Asthma self-care practices are detailed in children,[33-36] but less so in adults,[37] particularly in the use of innovative technologies such as gamification[38] to motivate the health consumer.

Stanford University's Self-Management Program[39] provides a framework from the Stanford Patient Education Research Centre for monitoring the progress of consumers undertaking self-care without health apps. For example, the program provides strategies to deal with frustration and communication between the patient, healthcare professional and patient's family. However, there is no evidence of differentiation between positive, negative and neutral user experiences; understanding of these experiences is key to the iterative design process. The authors reported a "cost-to-savings ratio of approximately 1:4"[39] from the program, with the results sustained for up to three years, a longer follow-up period than many clinical trials.

1.2.1 eHealth Literacy in Self-Care

Consumers require a certain level of technological literacy before they can commit to, and appropriately use, health technologies. Technological literacy is defined as the measure of one's competency using technology such as mobile apps.[40] There is evidence to suggest technological literacy is influenced by demographic characteristics of the consumer.[4,41-43] The implications of eHealth literacy are stipulated in Sections 1.3 and 1.3.1.

As of 2017, a 21-item Dutch instrument measuring “digital health literacy” as a self-report scale against seven components such as “navigation skills”, privacy, and reliability was published, connecting the continuum of traditional “information gathering” to web interactivity.[44] This eHealth instrument provides a holistic self-appraisal opportunity before consumers can commit to more complex eHealth technology, for example, asking whether “click[ing] something” results in an unexpected result or questions surrounding consumers’ use of a mouse or buttons.[44]

App-specific questions pertaining to the use of mobile technologies rather than eHealth websites are not explicitly covered in the 21 items. The authors recognised this limitation since most study respondents accessed [health] information using a mobile device.[44] Such an update could also incorporate Health 4.0 such as virtualisation and Big Data rather than only Health 2.0,[45,46] accommodating for advances such as therapeutic diagnostics, or “theragnostics” by providing clinicians with historical consumer “motoric and cognitive performance.”[47] One example of Health 4.0 active in a hospital setting is the “OmaMehiläinen” mobile app in Finland, connecting to user’s health records. “OmaMehiläinen” fulfils consumer medical needs including the feature to book physical appointments with clinicians, undertake virtual appointments, manage pharmaceutical prescriptions, includinghome delivery; the partial coverage from insurance companies[48] is a desirable feature suggested in Section 7.3.

Consumers’ *health literacy* is arguably equally important in self-care using monitoring devices. Health literacy encompasses the ability to absorb, synthesise and critique health information to improve decision-making in situations ranging from following a course of medications to long-term self-management.[49,50] Health literacy presents a component of eHealth literacy and can affect how consumers undertake self-management.[51,52] Health literacy is an “overlooked problem in healthcare.”[53] Health literacy was generally poor when the internet was gaining momentum,[54] and is considered still not high enough today.[55] Benefits of greater health literacy include consumers being more aware of medical terminology and the ramifications of their actions on their health condition, as well as greater confidence[56] in managing their condition and fewer medical incidents.[57]

1.3 Mobile Applications in Self-Care

Self-monitoring utilises parameters such as heart rate, blood pressure, sleeping patterns and blood glucose. Most technologies require peripheral devices to capture these data. The majority of health-related apps are targeted towards fitness monitoring,[58] and measure variables such as heart rate, blood pressure and distance travelled. Common features include an online user profile, capacity to enter readings/scores, background information and visual outputs such as graphs. The demand for clinical outcomes to be accurately measured has resulted in an increase in devices capturing "glycaemic control, medication adherence, and preventive services,"[3] requiring eHealth literacy to interpret and action collected data.[42] Other metrics exist to increase motivation and persistence with self-documentation, and commonly include social media[59,60] integration to collate and compare users' achievements. Integration with social media requires sharing of data, which may not be acceptable for some health consumers.

The ever-increasing number of fitness apps is likely related to market demand and capacity to link with business offerings such as health insurance plans.[61] Health professionals have traditionally been capable of acquiring, maintaining, transferring and utilising patient data.[62] However, with the introduction of mobile apps integrating with smart, wearable devices, the aims are now to upskill the health professional workforce and to optimise data flow through intuitive user interfaces and data management protocols.

The status of apps before the 2013 – 2015 literature review in Chapter 1 and before the 2016 – 2018 literature update in Chapter 6 is informed through the 2012 Fox and Duggan report.[63] This report stated 38% of respondents used health apps for fitness-related goals such as "exercise, fitness, pedometer or heart rate monitoring," while 31% exhibited more dietary inclinations such as calorie counters and diet-specific apps. Other uses such as menstrual cycle monitoring, blood pressure and mood did not indicate whether these were chronic conditions or merely tracking as part of the self-care paradigm for good health.[64] These results are of interest when compared to the qualitative study in Chapter 2,[65] where four of the most frequently used apps were all fitness-related and in some cases, were used to manage a chronic disease such as diabetes or hypertension.[65]

1.3.1 Limitations of Health Apps

Most apps rely only on cognitive input, i.e. they require users to enter self-perceived (subjective) and/or observed data. This is a fundamental limitation in health care for chronic conditions with measurable parameters, since biofeedback[66] is necessary to gain optimal understanding of the consumer's condition[67] at any given time, and provides more objective measurement. For example, even if consumers are feeling well, their biofeedback metrics may suggest otherwise. For conditions such as asthma, it may be appropriate – and valuable to health professionals – for app users to document periods of discomfort and shortness of breath. For diabetes, biofeedback mechanisms can guide users' requirements for insulin dosing. Disparity between subjective cognitive data and objective biofeedback data is expected to complicate the further development of biofeedback peripheral devices for mobile apps. Such issues require resolution before an innovation is considered effective for a population group. One solution is to provide adaptive user interfaces through Artificial Intelligence (AI) to predict user tasks.[68,69] This is a long way from integration with chronic disease apps for Australian consumers.

Some currently-marketed fitness apps can facilitate basic self-care tasks via tabulating data over a period of days; however, more support is needed from corporate partners to integrate dedicated chronic disease apps with product offerings such as health care plans. Limitations of reported research include a limited number of apps being downloaded and tested for usability,[70] since it is not practical to test all apps for one study. Furthermore, in a number of studies,[71-74] the app in question was custom-developed for that trial, without head-to-head comparison with existing apps. User feedback ratings and internal product evaluations only represent a basic level of testing. Additionally, some apps undergo updates during the research; whilst some updates are 'bug fixes' with no user interface changes, other updates involve new app features and layout. For those papers outlining positive and negative aspects of self-monitoring technologies,[75,76] neutral user experiences are not explored. It is important to identify neutral user experiences to work towards minimising negative experiences and maximising positive use cases.

The World Wide Web (WWW) Consortium, an international community to develop web standards[77] has created guidelines to optimise accessibility[78] of web pages for people with disabilities; these guidelines may be useful in the evaluation of apps. By performing more consumer-based testing, “low consumer tolerance,”[79] resulting in reduced use of the app, can be mitigated. With regard to human-computer interaction for healthcare, there are numerous guidelines listing parameters such as suitability[80] for users with limited health literacy[81] and/or technological literacy. Self-care technologies that independently monitor one’s health and transmit data to a healthcare provider are increasingly important. From review of self-care studies, it is imperative to immerse the user within the first week of engagement and ensure changes in outcomes measures such as quality of life are maintained, as chronic conditions require ongoing care.[65]

1.4 Australian Health Review Manuscript; Literature Review

This sub-section contains the Literature Review as the peer-reviewed *Australian Health Review* publication.[82] Permission for reproduction of the published paper is provided in Appendix 1: Journal Consent Forms. An update to the existing body of knowledge has been provided in Chapter 6.

CSIRO PUBLISHING

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Contribution of mobile health applications to self-management by consumers: review of published evidence

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Abstract

Objective. The aim of the present study was to review the contribution of mobile health applications ('apps') to consumers' self-management of chronic health conditions, and the potential for this practice to inform health policy, procedures and guidelines.

Methods. A search was performed on the MEDLINE, Cochrane Library, ProQuest and Global Health (Ovid) databases using the search terms 'mobile app*', 'self-care', 'self-monitoring', 'trial', 'intervention*' and various medical conditions. The search was supplemented with manual location of emerging literature and government reports. Mapping review methods identified relevant titles and abstracts, followed by review of content to determine extant research, reports addressing the key questions, and gaps suggesting areas for future research. Available studies were organised by disease state, and presented in a narrative analysis.

Results. Four studies describing the results of clinical trials were identified from Canada, England, Taiwan and Australia; all but the Australian study used custom-made apps. The available studies examined the effect of apps in health monitoring, reporting positive but not robust findings. Australian public policy and government reports acknowledge and support self-management, but do not address the potential contribution of mobile interventions.

Conclusions. There are limited controlled trials testing the contribution of health apps to consumers' self-management. Further evidence in this field is required to inform health policy and practice relating to self-management.

What is known about the topic? Australian health policy encourages self-care by health consumers to reduce expenditure in health services. A fundamental component of self-care in chronic health conditions is self-monitoring, which can be used to assess progress towards treatment goals, as well as signs and symptoms of disease exacerbation. An abundance of mobile health apps is available for self-monitoring.
What does this study add? A limited number of randomised control trials have assessed the clinical impact of health apps for self-monitoring. The body of evidence relating to current and long-term clinical impact is developing. Despite endorsing self-care, Australian health policy does not address the use and potential contribution of mobile health apps to health care.
What are the implications? Widespread and sustained use of validated mobile health apps for chronic health conditions should have potential to improve consumer independence, confidence and burden on health services in the longer term. However, a significant body of scientific evidence has not yet been established; this is mirrored in the lack of acknowledgement of health apps in Australian health policy referring to consumers' self-management.

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Introduction

With Australia's retirement age and life expectancy extending, the ability to independently manage one's health is increasingly important. Commitment to this activity will help relieve pressure on hospital services if people become more aware of changes in their condition and self-manage these changes in the community before requiring formal assessment and management.[1] The capability of health consumers to manage their condition in the community environment is referred to as 'self-care';[2] this phenomenon is expected to be increasingly important for people with chronic conditions such as sleep apnoea and diabetes.[3] Consumers and researchers are becoming more aware of the need for self-care[4] and its short- and long-term benefits.[5] In order for self-care of a chronic condition to be sustained, self-care techniques need to be integrated into one's life.[6,7]

Self-monitoring is a fundamental component of self-care in chronic conditions.[8] Self-care often requires self-monitoring a chronic condition to effectively make daily decisions relating to medications and capacity for activities.[9] Whether referring to literature from the 1970s[10] or the present,[11] self-monitoring has clear potential to improve clinical outcomes for the patient.[12] Over this period, self-monitoring has experienced major developments in its practical immersion into one's lifestyle. Self-monitoring is an increasing trend, as evidenced by the international 'Quantified Self' movement (http://quantifiedself.com, accessed 3 November 2014) and has potential, when undertaken appropriately, to improve health care in Australia.[13] Initiatives such as the Quantified Self movement encourage self-documentation by health consumers at their individual level of health literacy and information and communications technology (ICT) literacy, commonly using wearable technologies or other monitoring devices.[14]

Despite the benefits of self-care, adoption of self-monitoring using mobile technology is challenging for people of certain physical location, literacy levels and age groups. Mobile telephone coverage is undergoing improvement in regional Australia as part of Telstra's Mobile Black Spot program;[15] it may take some time to realise this improvement in terms of consumers' health outcomes. Low literacy is generally associated with poorer health and underutilised health services.[16] This has been documented in Australia for children and senior citizens with carers of low health literacy.[17] A further challenge in the uptake of self-care was noted by an Australian study of female nurses aged 40–60 years.[18] Recurring themes in that study included 'you don't think of yourself first' and 'you just work around it [the health issue]',[18] suggesting self-management practices may even be challenging for health professionals.

There is a body of literature encouraging self-management using technology by adults with Parkinson's disease,[19] cancer survivorship,[20] headaches,[21] sleep conditions,[22,23] diabetes,[24] depression,[25,26] lung cancer,[27,28] chronic back pain,[29,30] chronic obstructive pulmonary disease,[31,32] arthritis,[33,34] stroke[35,36] and osteoporosis.[37,38] Asthma self-care practices using technology have been reported in children,[39–42] but less so in adults,[43] particularly in the use of innovative technologies such as gamification.[44]

Self-monitoring has the ability to capture health data from parameters such as heart rate, blood pressure, sleeping patterns and blood glucose. Most technologies require peripheral devices to capture these data. With the introduction of mobile applications ('apps') integrating with smart, wearable devices, health professionals now require operational knowledge of how a consumer's mobile app data can optimise data flow, and how to interpret these data for clinical management. User interface design and data management protocols may be particularly useful for consumers in remote or regional Australia, whose use of apps for self-monitoring could save time commuting for non-emergency medical visits.

Moreover, if the quality of health monitoring apps can be assured, and the reliability and validity of consumers' self-monitored data determined, the use of health apps for self-monitoring would ideally become integrated into routine consultations with health professionals, and endorsed in policy relating to self-management by consumers. The present mapping review investigates the contribution of mobile health apps to consumers' self-management of their chronic health conditions and the potential for this practice to inform health policy.

Methods

A mapping review was deemed appropriate for this analysis to 'categorise existing literature',[21] identify research gaps and subsequently inform policy makers of the state of evidence.[21] Mapping reviews differ from systematic reviews in that mapping reviews are more concise with briefer narrative analysis, do not offer an 'exhaustive and comprehensive' search strategy and are not bound by guidelines such as those of the Cochrane Collaboration.[21] As such, mapping reviews offer more flexibility to 'map' the extant literature. Similar to other types of reviews, the search strategies constrain the scope and date of publications included in the review.

A literature search was conducted to locate clinical trials and other intervention studies using or testing mobile apps for self-care by health consumers. Clinical trials are the recognised 'gold standard' for experimental design.[45] Databases interrogated were MEDLINE, ProQuest, The Cochrane Library and Global Health (Ovid), using the search terms and strategy given in Box 1. The search was limited to English-language peer-reviewed reports from 2013 to 2015, this date range recognising the influx of apps to the market in recent years.

Initially, duplicate papers were removed, then titles were scanned to search for relevance and abstracts were read to identify studies reporting outcomes from the use of health apps for self-monitoring in chronic conditions. Mobile health app studies included in the review were those that used a mobile app downloadable from an app store such as Apple's App Store™ or the Android Play Store™, including custom-designed Android and Apple apps that were made available to study participants via restricted access to an app store. Web-based self-monitoring software was excluded, in keeping with the principles of mobile apps being accessible in a native form for offline use.

The screening process excluded studies not involving a chronic condition, not health related, without an abstract or summary or using an intervention based only on text messaging, Internet browsing or telephone calls. In addition, study protocols without results were excluded.

The search of academic literature was supplemented by manual scanning of electronic alerts relating to emerging literature, as well as online search of policies, procedures, guidelines and government reports from Australian Government and state Department of Health websites and disease support group websites, such as Rare Voices Australia (https://www.rarevoices.org.au/; verified 23 November 2015) and the Genetic and Rare Disease Network (http://www.geneticandrarediseasenetwork.org.au/; verified 23 November 2015), to identify content referring to the use of technology in self-care.

The headings in this review were determined *a priori*, with literature organised by disease state. As per mapping review

Box 1. Search strategy

- 'mobile app*' OR 'mobile phone' OR smartphone OR 'smart phone' OR 'mobile device', AND
- 'self care' OR 'self monitoring', AND
- hypertension OR 'blood pressure' OR cardiac OR heart OR depression OR anxiety OR mood OR diabetes OR pain OR asthma OR menstrual OR period OR smoking, AND
- trial OR intervention

methods,[21] gaps in research were identified to propose future directions for research and policy.

Results

Using the search terms listed in Box 1, 64 papers were identified, comprising 33 from MEDLINE, 24 from ProQuest, three from Global Health (Ovid) and four from the Cochrane Library. No additional papers that met the inclusion criteria were identified from the emerging literature. One relevant Cochrane review was identified;[46] this paper comprised two randomised control trials (RCTs) applying mobile apps in asthma management[47,48] that were substituted for the Cochrane review in the pool of papers. Nine duplicate papers and six protocol papers (without results) were excluded. From the remaining 50 papers, screening by title and abstract identified 13 relevant papers. Of these, nine papers were excluded following review of the text, leaving four papers. Three reported trials in asthma, and one was for a trial in diabetes.

Grey literature searches of sources including government health policy, procedures and Western Australian Department of Health guidelines revealed several comprehensive self-management strategies,[49,50] but no reference to, or therefore support for, mobile health applications.

Asthma

In a Canadian single-centre, pre-post intervention for asthma patients, Licskai *et al.*[51] created a platform-agnostic mobile app, referred to as the Smart Phone Application (SPA), with consultation from an expert committee, enabling interactive decision support for people with asthma. That study focused on dynamic 'knowledge translation', which was considered lacking in static, paper-based asthma action plans. The premise for the study was that real-time asthma action plan entries can provide functionality, such as 'decision support, interactive feedback and medication adherence reminders' not available using traditional, paper-based action plans.[51] The primary outcome was the data volume received by the server from the participant's input. Daily peak flow readings were manually entered into this app and asthma control was determined using a 7-day average questionnaire, as per the Canadian Asthma Consensus Guidelines,[52] and was achieved by 18 of the 22 participants. In addition, 18 of the participants indicated SPA '. . .is ready for use by people with asthma' and 'almost all' participants would continue using the app.[51] The Mini Asthma Quality of Life Questionnaire (AQLQ) of Juniper *et al.*[53] was also used in that study,[51] and the scale demonstrated a significant increase in quality of life (QoL) from 4.3 to 4.8 (of a maximum score of 6; $P<0.05$).

The aforementioned Cochrane review[46] of two RCTs of tablet and smartphone apps for asthma management indicated a paucity of research in self-management practices and mixed evidence regarding the effectiveness of apps for asthma management. Statistically significant changes in adherence to study participants' asthma action plans when using asthma apps were not consistently found between the two RCTs.

One of the component studies, from England by Ryan *et al.*,[48] involved 140 participants using the custom-designed t+ Asthma app and 141 using paper-based monitoring. Participants using the t+ Asthma app entered two daily peak-flow readings in exchange for immediate feedback via a 'traffic light' system.[48] Participants were provided a PiKo™ meter (nSpire Health, UK) for lung function testing (forced expiratory volume (FEV)) throughout the trial. Participants who reached the amber zone twice, or the red zone once, within the study period were telephoned by an asthma nurse, illustrating the interface between self-monitoring and clinical care. The authors compared the mobile app group and the paper-based group for all outcome measures. Results indicated a non-significant change in QoL scores using the Mini AQLQ[53] at the 6-month follow-up for the mobile app group from 4.25 to 5.00, compared with the paper-based group scoring 4.34 at baseline and 4.99 at 6 months.[48] However, no significant changes were demonstrated in either group regarding asthma control using the Asthma Control Questionnaire[54] (ACQ; mobile app group 0.75 vs paper group 0.73) or self-efficacy using the Knowledge, Attitude and Self Efficacy Asthma Questionnaire (KASE-AQ;[55] mobile app group –4.4 vs paper group –2.4).

The other RCT in the Cochrane review, a 6-month study by Liu *et al.* in Taiwan,[47] found 'incremental improvement' in peak expiratory flow rate from 4 to 6 months after the intervention. In all, 89 participants were recruited to that study, with 43 allocated to the mobile app group and the remainder to the control group, who used a paper-based booklet and action plan. The researchers referred to the app, developed by the Taiwan Chest Disease Association and the Taiwan National Center for High-Performance Computing, as the 'mobile telephone-based self-care system'.[47] The FEV increased among the mobile app group at 6 months ($P<0.05$). The Short Form-12[56] was used to measure QoL, in addition to pulmonary function tests. The mobile app group demonstrated a significant increase in QoL using the Physical Health subscale of the SF-12,[57] from a score of 41.6 at baseline to 45.2 after 2 months ($P<0.05$), increasing monthly, but not in a consistent or sustained manner over 6 months.[47] Future studies should consider incentivising participants to improve engagement, aiming to sustain their improved QoL. Although no user feedback was reported, the authors indicated the app was user friendly and 58% of participants preferred a mobile-based solution.[47]

The two RCTs had limitations with 'blinding of participants and personnel' to 'participants' performance and the observed effect'.[46] The authors of the Cochrane review echoed recommendations by the authors of the original studies in supporting the use of technological innovation to enhance adherence to asthma management. Future studies should include multicentre recruitment to capture results from more diverse settings and participant demographics. In addition, explanation of data security in these apps would be useful to understand the system architecture.

Diabetes

The one trial reporting evaluation of a mobile app in diabetes[58] was an Australian RCT involving adults with type 1 diabetes, with 3-monthly follow-up. The authors claimed that use of the publicly accessible free mobile app (Glucose Buddy), in addition to weekly healthcare professional communication via traditional text messaging, '. . .significantly improved glycaemic control'.[58] The control group did not use an app or receive text messages. Glycaemic control was recorded at four time points (baseline and then after 3, 6 and 9 months) and was assessed by HbA1c levels through a pathology laboratory. For the intervention group

($n=25$), the baseline mean HbA1c of 9.1% improved significantly to 8.0% at 6 months and 7.8% at 9 months. The control group ($n=28$) recorded a baseline mean HbA1c of 8.5%, and a follow-up mean of 8.6% at 9 months.[58] The authors postulated providing the intervention group more than one avenue to record their glycaemic reading (mobile app and website) increased data accuracy and promoted continuity of data entry. No significant results were demonstrated for QoL and self-efficacy. High engagement levels by the intervention group were noted, although these decreased during the trial.[58]

Discussion

The key feature of mobile health apps is their capacity to provide social and clinical support for the consumer and to document self-administered readings and symptoms. The process of self-documentation should enable health consumers and their healthcare professionals' greater insights into control and management of chronic medical conditions. There is a developing body of evidence supporting the use of apps to facilitate self-care among consumers with chronic conditions. Given the paucity of published formal trials and the burgeoning app market, this field of research is likely to expand significantly in coming years. This is evidenced by several protocol papers identified using our search strategy describing in-progress studies. The strength of this evidence is dependent on well-designed trials and robust, valid mobile apps.

Our search strategy incorporated a range of common health issues that benefit from self-monitoring; this is a novel addition to the literature. Previously, the most comprehensive paper reporting the contribution of apps to health care was the 2013 Cochrane review[46] of two studies involving asthma management apps. Our search located a further two completed trials (in asthma and diabetes), and potentially several more, that reported findings from published protocols. The mapping review method enabled a narrative overview of the extant literature. Although each trial included was critiqued, one limitation of this method is the absence of robust quality assessment of these studies.

The present review only considered native apps, downloadable from Apple's App Store™ or the Android Play Store™. As such, trials reporting web-based apps were excluded; several of these were work in progress.[29,59–64] Native apps provide three advantages to their web app counterparts.[65] First, native apps can be accessed through a device's app store, which provides a more user-friendly experience when 'searching, purchasing, installing, or rating apps'.[65] Second, native installations can communicate with other protocols using an application programming interface,[65] for example using the device's camera and contacts database and connecting to other services and peripheral devices. Third, provided that native apps are well tested and robust, they offer a seamless user experience offline, with significantly reduced browser crashes.[66]

Three of the four studies reviewed described custom-designed, rather than commercially available, native apps. This is of interest when considering the proliferation of commercially available apps that are marketed solely on user feedback, rather than evidence of effectiveness when used to support self-care regimens. The abundance of commercially available apps lacking evidence of effectiveness opens opportunities for comparative evaluation of apps, and controlled trials of those deemed evidence based and robust. Sustained engagement and treatment adherence in self-care has been noted by the World Health Organization as a 'significant problem',[67] and it remains unclear whether mobile apps can indeed enhance health management in the community setting.

Comparison of studies

Of the four studies, three were RCTs and one was a pre-post intervention. Our search strategy was designed to identify studies involving a comparison group, rather than relying on user experience feedback. Despite the robust study designs, the asthma study by Ryan *et al.*[48] and diabetes study by Kirwan *et al.*[58] involved multicomponent interventions. A multicomponent intervention involves the intervention group using an app as the primary engagement mechanism plus an ancillary tool, such as advice from a medical professional. In these cases, the contribution of the app to participants' outcomes is unable to be distinguished. However, multicomponent interventions are reflective of how an app would ideally be used in a community setting; consumers would self-monitor their condition, with their health professional(s) reviewing these data and providing relevant advice.

It is important to appreciate the benefit of coupling app interventions with feedback from a healthcare professional, rather than leaving consumers to their mobile devices without periodic check-ups. It is feasible that a multifaceted intervention could generate more significant clinical and/or QoL outcomes in clinical trials involving apps compared with non-technological self-management. One technique to connect other consumers who have experienced their chronic condition is to merge value-added services to the health app. For example, a dial-a-doctor module within the health app itself provides the consumer an opportunity to extend the use of the health app. Participants providing and responding to feedback from healthcare professionals have been shown to complement app interventions, as evidenced by an American study combining social interaction via Twitter in addition to an app intervention.[68] Involving communication channels with health professionals via Twitter or a discussion forum can reassure consumers there is assistance where required.

All four studies reported one or more key clinical outcome measures. For diabetes, this was HbA1c,[58] a measure of longer-term control of blood glucose.[69] For asthma, clinical measures were asthma control, measured via the ACQ[54] (assessing the 7-day average of daily symptom scores and peak flow readings), and FEV, measured mechanically via a peak flow meter. These measures are common in disease management research, although they remain surrogate measures of true clinical outcomes, such as hospitalisations, disease-related complications and mortality. The validity of peak expiratory flow monitoring in asthma has been questioned in the past decade; although the measure is accessible and integral to self-monitoring, readings are technique dependent and persistence with self-monitoring has been reported as poor.[70,71]

User feedback was engaged in the RCT of Ryan *et al.*;[48] this provided participants a wake-up call when the ACQ was administered via telephone conversation. Participants considered their

ACQ score as a prompt for better self-care.[48] The Australian diabetes RCT involved 5 min of feedback per week per patient from a certified diabetes educator.[58] Enthusiasm from the research team for using real-time feedback was reported; however, this feedback was capped at 5 min, which is in line with a previous diabetes study.[72] It would seem appropriate to couple a mobile app intervention with feedback sessions, as per the diabetes study, to facilitate consistent engagement.

Humanistic measures (QoL, KASE-AQ and self-efficacy) were variably used in all four studies. Three of the four studies[47,48,58] reported increased disease control as a direct or indirect consequence of using an app for self-monitoring. All three asthma studies,[47,48,51] but not the diabetes study,[58] reported increased QoL. Neither study exploring self-efficacy[48,58] identified improvement in this measure. In addition, satisfaction with the app and message delivery rates were reported in one study.[51] Despite somewhat variable findings, the authors of all four studies advocated the use of mobile apps to facilitate self-care. More data are required to explore consumers' engagement with self-monitoring via apps and any association of self-efficacy with technological literacy and health literacy.

Health policy involving apps

Policy recommendations relating to the potential for mobile apps to assist management of chronic conditions also require more data. Although apps have been validated for use in headaches,[73] chronic back pain (FitBack; mobile web-based application),[30] diabetes,[74] Parkinson's disease (custom-made app PD Dr)[75] and asthma,[47,48] the lack of research into their contribution to clinical management and QoL is concerning.

The Australian government has been consistent in delivering services to improve chronic disease management,[49,50] particularly through primary care integration and commitment from healthcare professionals, the latter of which has been flagged in one Australian paper as a challenge in self-management programs.[76] It can be speculated that because of the rapid rate of launch of health apps, policy makers have not kept abreast with investment and policy strategies to incorporate mobile technology. To facilitate the policy decision-making process, broader immersion in the concept of self-care is recommended, commencing with inclusion in secondary school Health Studies curricula.[77] To cater for senior Australians, promoting greater use of mobile services such as the myDeduction app in conjunction with a myGov login account[78] and online shopping can ease entry to mobile self-management. In addition, community engagement can help uptake of self-management, such as local council-operated health and well being sessions tailored for seniors[79] and beginners.[80] Australian health policy makes reference to educational and non-technological self-care frameworks for the 2011–15 period.[49] However, health policies, strategies or guidelines discussing the contribution of mobile apps to Australian health care appear non-existent.

Conclusion

With increasing recognition of consumers' role in self-care, engagement with technology and investment in mobile health apps, it is plausible that development, endorsement and appropriate use of quality, evidence-based health apps could reduce burden in the health sector. Despite the abundance of health apps marketed, evidence for their contribution to health management is remarkably limited. To aid the decision-making process for updated health policy, a holistic, integrated approach is required, which includes catering for stakeholders with varying literacy and demographic characteristics. The few available studies advocate the use of mobile apps for self-management. Although Australian public policy addresses self-management educational programs, further studies are required to inform changes relating to health apps for consumers' self-management.

Competing interests

The authors declare they have no financial or personal relationships with organisations or people influencing this work.

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1.5 Relevant Theory

There are several theories applicable to self-monitoring in chronic conditions. Orem's Self-Care Model has been applied to chronic conditions to investigate "self-care abilities, self-care practices, and health outcomes."[83,84] However, this model lacks consideration of technological factors. The Health Belief Model (HBM), which refers to the perceived barriers and threats of the user's experience, has been used in studies of chronic conditions for investigation of medication compliance,[85,86] and is widely accepted. The PRECEDE-PROCEED model has also been applied in study of a chronic condition in Taiwan[87] to measure factors such as knowledge and self-efficacy plus lifestyle changes patients;[88] however, this model contains extraneous elements such as administrative and financial policies.[89]

The Health Information Technology Acceptance Model[90] is a health-specific adaptation of the Technology Acceptance Model (TAM)[91] which considers how consumers accept technology.[92] The TAM is an extension of the Theory of Reasoned Action, used to predict intended behaviour, in order to provide a technology-focussed paradigm in decision-making,[93] and has been applied in health-related studies on topics such as adoption of health apps.[94] Applying the HITAM alongside the HBM will be used to improve cross-disciplinary relevance and provide a more robust framework to assess mobile app usage and behaviour change in a chronic disease context. For example, user experiences are covered in the TAM (and HITAM) whilst HBM covers the perceived barriers and threats of the user's experience. Reflections on theoretical grounding used in this thesis are provided in Section 8.4.

1.6 Significance

With Australia's population ageing, interest in chronic condition management (asthma, diabetes, heart failure, cancer) with the use of technology is expected to increase. Methods to enhance self-care in the community will help relieve pressure on hospital services, and allow hospitals to focus on patients who require medical attention. Moreover, patients with chronic conditions who are capable of self-monitoring can enjoy more freedom in the community setting.

Given this research topic is an exploration of consumers' use of health technologies, it is expected that a number of topical and timely research recommendations will be identified, which will be of interest to consumers and healthcare providers alike. For health consumers, the expected outcomes include enhanced engagement with self-monitoring of their health conditions, through use of apps, leading to improved clinical management.

By including the consumer experience and product user interfaces in research, more accurate and holistic evidence can be generated for the development of best practices and Australian Standards.[95] For example, a faulty or illogical monitoring function in a health app may cause consumers to lapse with self-monitoring. If such factors remain unknown, consumers will not yield maximum potential from their device and are less likely to enjoy the independence offered by their self-care program.

1.7 Research Objectives and Questions

The overall aim of this research is to enhance self-management by health consumers with chronic conditions via use of mobile applications ('apps'). The specific objectives are to:

1. **Explore health consumers' interaction with health apps, via:**
    a. Semi-structured interviews with consumers with chronic conditions
    b. Thematic analysis of qualitative interview data
2. **Evaluate available health apps for a particular chronic condition, via:**
    a. Synthesis of a usability checklist (for health app quality)
    b. Creation of a protocol to replicate findings
3. **Evaluate and critically appraise health apps for a particular chronic condition, via:**
    a. Critical appraisal of health apps for that chronic condition (asthma)
    b. Validation of the protocol using another chronic condition (hypertension)

4. **Translate mHealth technology findings for industry via data synthesis from previous objectives, via:**
    a. An updated literature review relevant to the current mobile self-care environment
    b. Derivation of a mobile self-care concept map describing the mobile self-care eco-system.

2 CHAPTER 2: Exploration of Health Consumers' Interaction with Health Apps

2.1 Preface

This chapter incorporates the second paper published within the PhD candidature.[65] Permission from the journal, *PLOS ONE*, to reproduce the work is evidenced in Appendix 1: Journal Consent Forms.

This research stage addresses Objective 1a, "exploring consumers' interactions with health apps", and comprising semi-structured interviews. Methodological processes are described in the paper. Further information is provided below as a prelude to the paper.

Interview topics were informed by literature on consumers with chronic conditions, such as work by Scheibe and colleagues.[96,97]. No identifying, or potentially identifying, information was reported about participants. Demographic data were only collected for variables potentially associated with chronic disease management or app usage. Participation was voluntary, and participants were free to opt out at any time without ramifications. Token reimbursement for the participants' time was offered in the form of a gift card.

All participants were issued an Information Sheet (Appendix 2: Participant Information Statement) and provide signed consent (Appendix 3: Participant Consent Form). This study was limited to a predominantly tertiary-educated Australian perspective; apps marketed internationally may incorporate different user experience metrics."

Recruited participants were of a wide distribution of ages, in light of evidence that technological literacy is a function of age. Interview questions were available for the participant to read, ensuring clarity. Challenges in recruiting a more stratified sample size consisting of a more even age distribution representative of chronic conditions is noted as a limitation. However, attempts were made through the purposeful sampling by disseminating a call for participants through the National Asthma Council and Diabetes Australia.

2.2 *PLOS ONE* Manuscript

This sub-chapter presents the *PLOS ONE* paper published on 23 May 2016[65]. Details pertaining to participants' app usage is located in Appendix 4: Apps used by Participants.

PLOS | ONE

RESEARCH ARTICLE

Mobile Health Apps to Facilitate Self-Care: A Qualitative Study of User Experiences

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Data Availability Statement: Limited data can be made available to researchers who meet the criteria for access to confidential data. Due to the qualitative nature of these data, the interview transcripts contain personal information that potentially identifies participants and would breach participant confidentiality if made publicly available. Data requests may be sent to the corresponding author.

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Abstract

Objective

Consumers are living longer, creating more pressure on the health system and increasing their requirement for self-care of chronic conditions. Despite rapidly-increasing numbers of mobile health applications ('apps') for consumers' self-care, there is a paucity of research into consumer engagement with electronic self-monitoring. This paper presents a qualitative exploration of how health consumers use apps for health monitoring, their perceived benefits from use of health apps, and suggestions for improvement of health apps.

Materials and Methods

'Health app' was defined as any commercially-available health or fitness app with capacity for self-monitoring. English-speaking consumers aged 18 years and older using any health app for self-monitoring were recruited for interview from the metropolitan area of Perth, Australia. The semi-structured interview guide comprised questions based on the Technology Acceptance Model, Health Information Technology Acceptance Model, and the Mobile Application Rating Scale, and is the only study to do so. These models also facilitated deductive thematic analysis of interview transcripts. Implicit and explicit responses not aligned to these models were analyzed inductively.

Results

Twenty-two consumers (15 female, seven male) participated, 13 of whom were aged 26–35 years. Eighteen participants reported on apps used on iPhones. Apps were used to monitor diabetes, asthma, depression, celiac disease, blood pressure, chronic migraine, pain management, menstrual cycle irregularity, and fitness. Most were used approximately weekly for several minutes per session, and prior to meeting initial milestones, with significantly decreased usage thereafter. Deductive and inductive thematic analysis reduced the data to four dominant themes: engagement in use of the app; technical functionality of the app; ease of use and design features; and management of consumers' data.

Conclusions

The semi-structured interviews provided insight into usage, benefits and challenges of health monitoring using apps. Understanding the range of consumer experiences and expectations can inform design of health apps to encourage persistence in self-monitoring.

Introduction

The increasing aging population will benefit from 21st Century self-care techniques, easing burden on healthcare by enabling self-monitoring at home, office or other location.[1] In order for self-care of a chronic condition to be sustained, self-management techniques need to be integrated into one's life.[2, 3] Due to differences between chronic conditions, there is no agreed definition of self-care.[4] One commonality is that self-care requires *self-monitoring* for a consumer to pursue daily decisions to maintain functionality.[4] Self-monitoring can be conducted by consumers on various levels; examples are self-awareness of symptoms (e.g. shortness of breath), manual blood pressure readings, and self-maintained electronic databases of blood glucose measurements in diabetes management. For consumers with reasonable health literacy, self-monitoring offers greater autonomy, aiming to reduce pressure on health resources.[5–8]

Despite being a relatively new phenomenon, self-monitoring has experienced notable developments in its practical immersion into one's lifestyle. Health consumers are increasingly engaging with mobile health applications ('apps')[9] for self-monitoring. However, limited regulation in the technology marketplace enables insufficiently tested[10, 11] self-monitoring devices to be launched, with potential for health consumers to ill-advisedly change their self-care regimens. There are many instances of 'buggy' health apps.[10, 11] Indeed, a number of authors have called for guidelines around electronic self-monitoring to prevent errors or other incidents.[12, 13] In Australia, the introduction of the Health Market Validation Program[14] signifies the Victorian State Government's and technology vendors' commitment to remote/home monitoring; feasibility studies are required in other jurisdictions.

Research incorporating Consumer Experience Metrics

One report, in which consumer experience with health apps was a key outcome, describes two Swiss university randomised pragmatic trials.[15] Both studies explored whether an app-based intervention was more effective than self-management of chronic pain without an app. The apps included modules for participants to write diary entries and complete questionnaires during the six-month intervention. Consumer experience was measured in terms of adaptability and pre-post sick leave,[15] with the Chronic Pain Acceptance Questionnaire[16] used to record sick leave taken by participants.

Consumer experience was also included in a four-week British weight management study involving seven females and six males.[17] A hybrid website and smartphone app were trialed. Semi-structured telephone interviews were used to assess the two platforms, with data analyzed via inductive thematic analysis.[17] Participants noted improvement in self-reported dietary and physical activity. No confounding factors relating to weight management were acknowledged. Key outcomes relating to goal engagement included motivation, self-efficacy, awareness, effort and achievement. The researchers encouraged critique of the app, whereby participants suggested use of barcode scanners and free-text entry boxes.

Since self-care transfers most of the responsibility to the consumer, the usability of technology for this purpose is imperative. Consequently, self-care technologies need to be adaptable to technological environments and user preferences.

A growing number of studies have explored the impact of technological interventions on consumers' health outcomes. These interventions have included automated reminders (via text messaging)[18, 19] and internet-based information,[20] and have been assessed using self-report by participants,[21] with little, if any, external validation. Poor persistence with long-term self-monitoring is evident in chronic conditions such as asthma.[22] Gamification can be used to increase engagement through use of rewards for repeat logins within a period of time and achieved milestones.[23] With many usability features conceived to date, mobile health app design is constantly evolving;[24] many app development frameworks offer fast, scalable interfaces to deploy changes to user interfaces seamlessly.

An American health app study reported sociodemographic characteristics of app users, through a 36-item cross-sectional survey of 1604 English-speaking adults.[25] At least one health app had been downloaded by 934 of the participants. Data from open-ended questions, such as effectiveness of the app and reasons for halted use, were thematically analyzed by two researchers, and revealed Weight Loss, Calorie Tracking, Nutrition, and Physical Activity as their main themes. While facilitating statistical analysis, large-scale studies are compromised by their limited ability to probe participants for in-depth responses.

Studies into self-care using mobile apps have predominantly involved custom-designed apps. Examples are a pre-post intervention for asthma using the *Smart Phone Application*,[26] randomised-controlled trials for asthma using the *t+ Asthma* app[27] and another unnamed purpose-built app,[28] as well as a diabetes randomised-controlled trial using *Glucose Buddy*.[29] In these studies, self-efficacy was the only measurement of consumer experience, while participants' engagement with the app was determined via self-report. Engagement does not necessarily mean long-term commitment to using the app; therefore, combining such data with usage statistics, such as login time and frequency and accessed features would add value to these studies. In contrast, mobile app-based obesity management in South Korea[30] applied the purpose-built *obesity-management app* constructed with 'knowledge statements' from an expert committee. Other custom-designed apps include an app for self-monitoring and guiding lifestyle management for breast cancer survivors[31] and PD Dr, a home-based monitoring assessment system for Parkinson's disease.[32]

Notable deficiencies collectively demonstrated in these studies are their relatively short follow-up periods and lack of detailed consumer experience findings. Additionally, self-management programs have measured select outcomes, rather than a more holistic spectrum of outcomes relevant to conditions such as diabetes, osteoarthritis and hypertension.[4]

Theoretical Frameworks

The Technology Acceptance Model (TAM), published in 1989, quantifies how consumers accept technology.[33] It is an extension of the Theory of Reasoned Action,[34] and is used to predict intended behaviour, adopting a technology-focussed paradigm in decision-making.[35] The TAM has been applied in qualitative[36] and quantitative[37] studies of health apps to determine the acceptance of mobile technology amongst physicians and medical students, respectively, and in health-related studies on topics such as adoption of health apps.[38]

The Health Information Technology Acceptance Model (HITAM) is an evolution of the third version of the TAM for the health technology field,[39] combining behavioural, personal, social and IT factors. This model also embraces the Health Belief Model[40] and has been used in asthma studies for investigation of medication compliance.[41, 42] However, no literature was found in which the HITAM informed research into the use of health apps.

The Mobile Application Rating Scale (MARS) is a validated and reliable scale[43] due to its internal consistency, inter-rater reliability and comprehensive extraction of 25 papers and resources in its formation. The MARS is an Australian development from 2015 to assess the quality of health apps, and is based on four quality scales: engagement, functionality, aesthetics and information quality. Research applying the MARS in studies involving health apps is emerging, with MARS noted in an Australian wellbeing evaluation protocol[44] and mentioned in an Irish mental health app feasibility study without being used in the study itself.[45]

Other theoretical models and frameworks have been applied in studies of self-care. The PRECEDE-PROCEED model has been applied in an asthma study in Taiwan[46] to measure factors such as asthma knowledge and self-efficacy; this model contains elements such as administrative and financial policies that may not be relevant to exploratory research.[47] Similarly, Orem's Self-Care Model has been applied to asthma to investigate "self-care abilities, self-care practices, and health outcomes."[48] However, this model and the PRECEDE-PROCEED model lack consideration of technological factors.

Review of the literature suggests the TAM, HITAM and MARS are the most relevant frameworks to qualitatively explore consumers' experiences of mobile health apps. While no published research has applied a combination of these models, integration of the TAM, HITAM and MARS should improve cross-disciplinary relevance and robustness, and provide theoretical grounding for exploratory research into the consumer experience with health apps.

The objectives of this study were therefore to 1) qualitatively explore consumers' experiences with mobile health apps and 2) their perceived benefits from use of health apps, and 3) formulate suggestions for improvement of health apps.

Materials and Methods

This study explored consumers' experiences with health apps through semi-structured interviews. The Human Research Ethics Committee of Curtin University approved this study (approval number RDHS-102-15). In accordance with this approval, participants provided signed informed consent for interview.

Inclusion criteria were minimum 18 years of age (no maximum), residence in the metropolitan area of the University (for convenience), conversational fluency in English, and recent (at least one month's) experience with any health/fitness mobile app. Any duration of use of the app(s) was of value, because discontinued use and negative experiences complemented data from persistent users. It was intended to involve participants of a broad age range to combine experiences of the tech-savvy younger generation with the older generation.

Including fitness apps enabled participants with chronic conditions such as obesity, diabetes and high blood pressure to elaborate on their experiences without restricting them to disease-specific apps. Participants without a chronic condition were included to capture fitness app usage amongst chronic disease consumers and healthy counterparts.

Guiding the research was the post-positivism worldview where relationships can be reverse-engineered via tested approaches such as deductive analysis.[49] A reductionist philosophy was applied to deconstruct implicit and explicit responses into manageable variables. The qualitative paradigm was crucial to appreciate, observe and deduce consumers' experiences. The use of individual interviews offered privacy, and enabled exploration of each user's interaction with their identified health app(s). Semi-structured interviews provided participants freedom to elaborate on the interview guide (Table 1).

Table 1. Interview Guide.

Question	Elaboration Questions	Theory, study or construct
Which health app(s) have you used?	Do you still use that/those app(s)? (If multiple apps) Which of those apps are still on your device? Which of these do you still use? Which one(s) would you like to talk about today?	Experience
(If on present device) Please show me how you use your health app.	How did you set it up? What problems do you recall in setting it up? (Prompts: user interface, prompts, permissions, language used)	Technological literacy
For approximately how long have you used (did you use) this app?	How often do/did you use it? (If discontinued) Why did you stop using the app?	Experience
How did you 'discover' this app?	(Prompts: health prof recommendation, peer/family recommendation, self-search)	TAM—subjective norms[50]
On which platform do/did you use this app?	(Prompts: iPhone, iPad, Android phone, Android tablet)	Descriptors of use
What do/did you like about this app?	Does/did the app fulfil your needs? Why or why not? Do/did you enjoy sessions with your health app? How is/was working with your app satisfying? Is/was your health app worth recommending to others?	TAM—usefulness;[50] Mobile App Rating Scale[43]
How easy is/was using your app?	What makes/made the app information clear and understandable? How do/did you find the font size and representation? How do/did you add remarks to your readings?	TAM—ease of use;[50] Acceptance Factors of mobile apps[51]
Have you sometimes not known (did you sometimes not know) what to do next with your app?	Are/were there any parts of the app you don't use, because they're complicated? What app features do/did you find unintuitive? Do/did you sometimes wonder if you're using the app the right way? Who do/would/did you turn to for help using the app (prompts: family, friends, or online forum)?	Technological literacy; Acceptance Factors of mobile apps[51]
Have you found any 'bugs' in your health app, or things it can't do?	If the app crashes or freezes (crashed or froze), is/was it easy to restart? Have you ever given up due to technical glitches? Have you ever contacted the company about any technical glitches?	Limitations of the app; Acceptance Factors of mobile apps[51]
How much sight and sound stimulation do/did you get from your health app?	(Prompts: graphs, things that flash up, reminders about personal targets, warnings, sound effects/reminders)	Mobile App Rating Scale[43]
What customization features would you like to see in your health app?		Mobile App Rating Scale[43]
What is your view of information stored on the cloud?	Do you find it an invasion of privacy?	
Describe your Initial user profile setup	Was registration via social media e.g. Facebook, Google + an option?	
Is your health app affiliated with a government health organization?	(Researcher to check later if participant unsure)	Mobile App Rating Scale[43]
Does/did your doctor (or other main health care provider) know you have used this app?	(If yes) How would you describe his/her reaction? Are you encouraged by a health professional (pharmacist, general practitioner) to self-reflect on your chronic condition?	Doherty[52] Design and Evaluation Guidelines
What medical or technical jargon have you seen in your app which you don't understand?		Doherty[52] Design and Evaluation Guidelines
Does your app use technology you are already familiar with?	Are the dialogue boxes and input fields similar to what you are used to?	Doherty[52] Design and Evaluation Guidelines
Do you feel you require a peripheral (plug-in or Bluetooth) device to operate your app more effectively?		Yin[53] Usability Risk Level Evaluation
Do you prefer tactile feedback (vibrations) over plain text feedback?	Have you noticed anything vibrate when you've done something wrong or you receive a warning?	Yin[53] Usability Risk Level Evaluation
What features of your app do you think conflict with each other?	(Prompt: inconsistent shortcuts)	Yin[53] Usability Risk Level Evaluation
Are you satisfied with the time taken to perform tasks on your app?	(Prompts: time to display graphs, time to synchronize information)	Yin[53] Usability Risk Level Evaluation
What age bracket are you?	18–25; 26–35; 36–45; 46–55; >55 years	
Your occupation?		
Your highest education?	Year 10 (junior high school); Year 12 (senior high school); TAFE (technical college); University	

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Constructs of the TAM,[33] specifically, perceived ease of use and perceived usefulness, were included in the interview guide. The HITAM included constructs describing personal and social factors such as motivation, self-reflection, competition and recommendation. Additionally, features of the MARS, such as engagement and aesthetics, were included. Duplicated concepts between the three models were deleted. Questions were adapted to suit this study, with the interview guide comprising core questions and supplementary questions for clarification and elaboration. The supplementary questions reflected "acceptance factors of mobile apps,"[51] collectively capturing all perceivable aspects of consumers' health app usage. Following independent review of the draft interview guide, the structure was revised to enable participants to reflect on more than one app during the interview.

Participants were a convenience sample of residents in the Perth metropolitan area, aged 18 years or older and conversationally fluent in English, who self-reported recent use of any commercially-available health/fitness app with capacity for self-monitoring and data input. Any duration of use was included, because discontinued use and negative experiences were considered to provide valuable insights into persistence, and complemented data from persistent users. No preferential sampling of participants with either negative or positive experiences was applied.

A multi-faceted recruitment strategy was applied. Participants were recruited via co-operation with health associations such as Celiac Australia and Diabetes Australia, through their social media accounts and eNewsletters over a period of four weeks. A local radio station popular with a mature demographic was also utilized in an attempt to recruit listeners with an interest in self-care. The first author's affiliation with a technology start-up hub enabled a broadcast announcement to members to attract participants from different educational backgrounds who shared a common goal to innovate. A static text advertisement was posted on the University portal, in addition to posters with a Quick Response Code at shared university computer workspaces and the library.

Interviews were scheduled in quiet locations such as a public library or participant's office. A single interviewer (author KA) conducted all interviews in June and July, 2015. The first several interviews were used to reflect on the question guide. Interviews were digitally recorded, supplemented with field notes and post-interview reflections. Data saturation was perceived through recurring explicit ideas[51] such as motivation, customisation, interconnectivity, data inaccuracy, convenience and competitiveness, and confirmed during analysis. Literature suggests 20–25 participants ranging generally provides adequate saturation of themes when using qualitative semi-structured interviews.[54–56] Advertising was halted after four weeks on-campus and seven weeks off-campus. Audio files were professionally transcribed by an accredited agency with privacy certification. Raw data files were imported to QSR NVivo 10 for open coding and analysis.

Braun and Clarke's six-step thematic analysis approach was utilised to capture user experience themes,[57] addressing Objective 1. The deductive approach[58] was applied to continually reflect on, and refine, emerging themes. The deductive coding framework was synthesized using the TAM, HITAM and MARS. Step One involved data familiarization to verify accuracy of transcriptions. This required the researcher to become intimate with the transcripts by re-reading them and referring to field notes. As per Step Two from Braun and Clarke, co-authors confirmed selection of codes and themes, and amendments were made as necessary to reach consensus. Initial coding was performed in NVivo based on the deductive coding framework, with miscellaneous responses interpreted inductively into new codes as required. Two authors matched initial coding to ensure consistency and establish common ground to confirm definition of the full set of themes. Step Three involved clustering nodes to a common theme(s) based on coherent patterns. To ensure robustness, data extracts are quoted in the Results section to demonstrate legitimacy of the identified themes.[57] Step Four involved reduction of themes into most prevalent implicit and explicit ideas.[57] Redundant themes derived from the three published models were deleted. Step Five involved describing the parameters of, and naming, the themes, whilst Step Six involved reporting to convey the analysis made. Outcomes from Steps Four, Five and Six are reported in the Results.

Data are presented based on emergent themes from thematic analysis, exploring how health consumers use apps for health monitoring (addressing Objective 1). Perceived benefits from use of health apps (addressing Objective 2) and suggestions for improvement of health apps (addressing Objective 3) are presented descriptively.

Results

Description of Participants

The most common age bracket of participants was 26–35 years; one participant was over 50 years and another recently turned 18 years old; further participant demographics are provided in Table 2. Interviews were completed in 20 minutes on average, during which time, most participants answered all questions relevant to their experience.

Table 3 displays the types of apps reportedly used by the 22 participants, three of whom did not report any chronic condition. Nine apps were self-discovered, and two recommended by friends, four by a family member or partner, four by a healthcare professional and one by information from a health association or gym. The remaining two participants were influenced by multiple sources for different apps: self-discovery then a friend; and partner then a gym. All participants located their app using the respective app store on their smart device. For commercial reasons, the marketed names of the apps are not reported here. Persistence with each health app ranged from "a couple of weeks" for a diabetes app to "over two years" for a pain management app.

The chronic conditions reported by participants included sleep disorders, chronic migraines, menstrual irregularities, chronic depression, arthritis and Behçet's disease. A number of participants reported more than one condition. Although the interviews focused on user experiences rather than their medical condition(s), participants were keen to share insights into their health as well as app usage.

One participant presented with the new Apple Watch®, seven participants presented with Android smartphones, and the remaining participants owned an iPhone 4, 5 or 6.

User Experiences

Four emergent themes are described below, based on deductive analysis with reference to the TAM, HITAM and MARS. The themes were named Engagement, Functionality, Information Management, and Ease of Use. Each of the four themes aligned with constructs of one or more of the three published models.

Engagement

Aligned with the MARS, the Engagement theme covers consumer interaction with their app, motivation to sustain usage, ability to self-reflect or write notes against readings, and social factors enabling competition with other users. Apps that can sustain positive behaviors and adapt to changes in consumer requirements were more likely to be used on a continual basis. This was particularly noted amongst users of pain, sleep and depression management apps. The following user of a blood pressure-monitoring app demonstrated persistence with his/her app:

Table 2. Participant Demographics.

Characteristic	Subcategory	Number
Gender	Female	15
	Male	7
Age (years)	18–25	4
	26–35	13
	36–45	2
	46–55	2
	>55	1
Total Participants	Met inclusion criteria	22
	Excluded	4
Interview Duration (minutes)	Mean interview time	20
	Shortest interview	15
	Longest interview	41
Smartphone Operating System	Android	7
	Apple	15
	Windows	0
	Symbian	0
	Linux	0
Main Language	English	17
	Other	5
Recruitment Source	Physical university posters and online staff/student portals	10
	National Asthma Council eNewsletter and social media (Facebook)	3
	Rare Diseases Australia eNewsletter	2
	Celiac Australia eNewsletter	2
	Diabetes Australia eNewsletter	1
	Perth start-up community (posters and daily notices blog)	4
	Pharmacy open 24/7	0
	Curtin University Radio	0
Occupation	Allied health	3 (podiatrist, psychologist and speech therapist)
	University student	5
	Other office-based workforce	9
	Retail	1
	Start-up innovator	4
Highest Education	High school	2
	University	18
	Other	2

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"I was diagnosed with high blood pressure . . . I've now been able to come off the medication, but I still monitor my blood pressure [documenting the readings into an app] just to make sure it's in a healthy range."
[P6]

Inability to engage with one's health app can result in declined usage:

"I do have some apps I don't use often, mainly because they've kind of bored me in a way. I'll just do an example: one fitness app shows you how to lose weight, but the way it's describing it, it's not what I'm after. It's one of those free apps I bought that—I thought [the fitness app]

Table 3. Types of Health Apps used by Participants.

Type of App	Used by Android Participant Number	Used by iOS Participant Number	Number of Participants
Blood pressure monitoring app (1 type)		P6	1
Diabetes monitoring app (2 types)		P2, P17, P20	3
Migraine management app (2 types)		P5, P8	2
Menstrual cycle monitoring (4 types)	P1, P22	P6, P4	4
Anxiety management app (1 type)		P13	1
Calorie management and weight loss monitoring app (5 types)	P1	P2, P3, P16, P20	5
Celiac disease management app (1 type)	P11		1
Sleep monitoring app (4 types)	P14	P6, P13, P21,	4
Pain management app (2 types)		P8	1
Cycling app (2 types)		P12	1
Fitness App (22 types)	P8, P9, P11, P14, P18, P22	P2, P3, P7, P9, P10, P15, P16, P17, P19, P20, P21	17
Other (saliva analysis kit)		P16	1

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would be great, but when you actually use it, it's not the same."
[P2]

Most participants reduced or stopped using their app when they were familiar with how to self-manage and did not require constant interaction with their app. This finding was evident in users of strength training and fitness apps, whereby users who had reached their goal were not stimulated to achieve further, as well as the following user of a pain monitor:

"I think the migraine one's probably outlived its usefulness for me, but the back pain one, I could still go back to that at any time. If I started to need to monitor my pain again in a systematic way, I'd still go back to it. But I haven't had back pain that's needed that."
[P8]

The same participant reported 'outgrowing' two pain-management apps:

"So they've [migraine and pain tracking app apps have] sort of exceeded their usefulness now, but initially they were very helpful. Well, initially I was using them to track migraine symptoms and to track the effects of medication. But now I know what most of my triggers are, and I know what medication works. I guess for me to use it again, it would have to offer something different. So maybe alternative management strategies to what I'm already doing."
[P8]

Convenience was found to be the main factor why participants engage with health apps, as exemplified by a participant who used a smartwatch app for weight management:

"I really want to have a more active lifestyle . . . Being able to just look at [the smartwatch] on the fly and going, 'Right, if it just means that I have to go move that little bit more, or I have to exercise that little bit more', I will do it, because you have a real-time gauge of how well you've done for the day. So that gets me going because the perceived barrier of just getting the thing done is a lot lower."
[P7]

With one exception [P8], all reported increased engagement when describing the social or competitive angle of their app by all participants. This phenomenon was noted for fitness trackers over other health monitors. Examples were:

"Yes, thankfully [I am socially competitive]. Bragging rights, unfortunately, count."
[P9]

"Whenever we do a weekend challenge, you always have a look at what the other person's doing and [their] competitive side. I just want to beat the other people I see on there, so [using the app] is quite a good motivator."
[P10]

Having to purchase an app was expected to increase users' engagement and persistence with the app. Two cases relating to this concept were of note. Participant 5 had experienced migraines for over 20 years, and used a migraine app for one year after recommendation from her neurologist who suggested using a migraine diary. Participant 16 was an app developer who used an app for weight management. Neither expressed concern paying for health apps:

"Usually apps are not expensive, they're usually under $5. So if you found something really good, you would definitely pay."
[P5]

"I'm prepared to pay for applications. As well as being in the software industry, I understand that it's people's livelihoods are attached to this. I use some free applications, but I often will pay for the upgraded or the purchased option."
[P16]

Functionality

Aligned with the MARS and HITAM, Functionality encompasses guidance provided by the app developers, aesthetics, annoying features, layout, navigation and tactile feedback. While Functionality and Engagement are subjective concepts, Functionality relates to more tangible physical features. One consumer found color-coding in outputs a useful function:

"These pink patches are REM [rapid eye movement] sleep. The green, which is the light sleep, is basically stage two sleep. The blue is your stage three, four sleep."
[P13]

Use of tactile, visual and sound feedback was divided amongst participants, based on consumer preference and task performed:

"Yeah [I haven't disabled the auditory alerts]. My running app will ping every so often . . . saying a friend has completed a run, or it's time for me to do a run, or something along those lines. [My app with a wristband device] sends me a little alert if I'm close to my goals, if I've got 2,000 more steps to go. [The auditory alert] doesn't really bother me. I just tune out."
[P9]

"I would find that annoying, yeah [push notification suggesting exercise]. I'd turn it off."
[P10]

App functionality is dependent on the environment in which it is used. For example, a participant using a cycling app did not use any tactile or sound feedback:

"I usually keep it [the smartphone with the cycling app] on my bike while I'm riding, so I can see the speed, and the time, and distance and things. I don't think I use any sound or anything like that."
[P12]

Reminders to upgrade app versions for greater functionality were deemed annoying:

"With [the weight management app], they always ask you to upgrade to Pro, so you get more advice and stuff, but that's really annoying."
[P1]

When asked about peripheral devices to synchronize with a diabetes app, a participant responded:

"That would be very helpful, yes."
[P2]

Despite well-received navigation and layout features, the physical requirements for apps to measure sleep duration and quality were inconvenient:

"You have to put it [the phone] under your sheet, on the mattress, or under your pillow, and I think I just always had that consciousness that my phone was there and I had to remember to turn [the app] on before I went to sleep and turn it off again when I woke up, and it just wasn't really contributing to good sleep hygiene."
[P6]

Some participants indicated inclination towards customizing app features to suit their requirements:

"I would love . . . to be able to record reps, and sets, and weights and things like that [if their running app were more customisable]."
[P3]

Information Management

Information Management is aligned with the HITAM, and describes reliability, privacy to third parties, data security at rest and in transit, and quality and quantity of data. Without acceptable information management processes, health apps would lack the ability to compute readings, analyse data accurately, reject false or faulty entries and securely manage data. Data security appeared highly valued by participants, but was generally dependent on the type of data. For example, self-documenting height and weight did not raise any concern, although concerns were raised around access to those data by health insurers. One participant [P8], who used a sleep management app, expressed some concerns about potential access to stored data. Another [P13] had created a separate account for services used to preserve privacy. A user of a menstrual cycle tracker [P4] was not comfortable with the prospect of her data accessed by third parties, while another was less concerned:

"I don't think about [data security], to be honest. This is going to sound terrible—maybe I'm just really naive . . . I don't know, it doesn't really concern me. Probably, it should."
[P22]

Similarly, the following participant did not have any significant concerns about data security relating to a fitness tracking app:

"Not in this instance [no concerns about cloud storage]. I think there's been a lot of hoo-ha about it. And this is a company; I've been with Apple for a long time. They've done a good job making consumers feel that their data is safe . . . for Apple, because the data is just used for the benefit of the consumer. It's not otherwise; I have no qualms about it."
[P7]

Counterbalanced against privacy issues, there was some gravitation towards apps interconnected with consumers' healthcare services, as one participant with chronic migraine explained:

"I think it's not so much the app, but it's where the app can go. . . If it's just an app in isolation, it doesn't have as much power [compared to] if it's something that you can feed into information that you need somewhere else."
[P5]

Apps interconnected with each other were also of interest:

"Yes, that would work. I don't mind that. [if her diabetes app was connected to an insurance provider]."
[P17]

The ability to send blood pressure readings to general practitioners for analysis was highly valued by a participant:

"What I really liked about the blood pressure app is that it's really easy for me to export my results and email them . . . and I've actually done that before for the doctor. He said, 'How are you tracking with your blood pressure?' I've just been over [to the clinic]. While I'm sitting there and the doctor's in clinic, [I] just email him a PDF straight away of my results. He's able to save that on his computer, so it's quite handy for him too."
[P6]

Glitches in accuracy were reported in some apps:

"I was actually overseas back in April, and for some reason, [the wearable device] keeps on syncing back to the time when I was Turkey . . . which is a bit inaccurate."
[P2]

Additionally, the ubiquitous nature of self-care apps captured all forms of movement, at times leading to glitches:

"I went go-karting a while ago and [the app] thought I did like a hundred flights of stairs and thousands and thousands of steps in the hour I was driving around . . . I know it's never going

to be exact, but if it's within a few hundred steps, then that's fine."
[P10]

The following consumer was familiar with environments instigating inaccurate heart rate readings, and was able to rectify the issue:

"Sometimes [the heart rate app] gives numbers that are definitely not right, and then I'm like, "Okay, the lighting was too low" and discard that. I've noticed when . . . you're really cold, or if the florescent lighting is coming on a funny angle that [the phone's camera] will sometimes not register that there's too little lighting, or that the situation isn't going to give a good [heart rate] reading. So I tend to do it [measure heart rate using the app] twice rather than once."
[P13]

Some participants were particularly keen on statistics, and utilized their data in a more sophisticated way than others who merely glanced at their graphs and charts:

"I think I'm the sort of person that I like to see the data around whatever problem I've got, just to help me understand it and monitor it. So I'm always really interested in seeing the statistic."
[P6]

"For me, the major interest was the ability to export my data and consume it, and interpret it, and analyse it in a set of third-party tools. . . "I use some of our heavier statistical analysis tools from work against the number of times I go running and get some insight there."
[P16]

The same participant [P16] particularly valued using existing phone hardware to measure heart rate and blood pressure:

"So this technology is a really interesting use of the phone. Obviously, the camera flash, and the camera, and the light weren't intended for that use [heart rate, blood pressure using the smartphone's flash and camera]. I quite like that an entrepreneur somewhere has seen that these pieces of technology can be used to create something different . . . I would be interested more in things like blood pressure and even . . . blood glucose levels, and some of the measurements which I suspect are probably useful for people with diabetes and what have you."
[P16]

Ease of Use

Ease of Use is aligned with the TAM, and includes concepts such as automation, convenience, fun and health literacy suitable to cater a range of consumers. Recurring patterns among the 22 participants included the desire to use the app, particularly until consumers had reached their self-management goal. Various app features were appreciated by consumers, for example:

"The audio cues [telling me my duration and distance on my running app . . . I really like them."
[P3]

Automation of in-app functions reduces time to perform tasks and was appreciated by all participants:

"I use . . . [certain health apps] because they're connected to wearables, so I don't have to do a lot of the data collection. It does it automatically for me and then feeds me back the information."

[P9]

Convenience was appreciated by one user in self-managing diabetes:

"This one's quite good because it helps you out with planning. It also has information on how you can upload what your blood sugar levels are like. And it even shows you meal-time goals, it shows you how much juice you can have, how many starchy foods, how much protein, but even suggests what you should have every day, which is helpful, and it shows you what you can do, because you may think, 'Oh, well, eight pieces of vegetables is a lot,' but when you look into it, it's not that much, really."

[P2]

Perceived Benefits. The analysis in this section represents the benefits of using a health app to facilitate self-care, analysed inductively from coded interview data.

Perceived benefits from usage of health apps included greater self-awareness of one's condition, easier integration of self-management in daily life, ability to send data to allied health professionals without repeated visits, the ability to view historical data without visiting a doctor, social motivation to improve fitness, and desire to customise app features to suit individual needs. Participants also expressed greater control of their condition, in this case, menstrual problems:

"I decided just to search and find out whether there was an appropriate app just to make life a little bit easier. . . my specialist had told me to keep track of any symptoms and the length of my cycle, so I just found [the menstrual cycle tracker] myself online, and found that to be an easy tool to use."

[P6]

Suggestions for Improvement. Suggestions for improvement were identified deductively from responses, and were not constructs of the TAM, HITAM or MARS. Suggestions included:

"[The diabetes app] could remind you when to do your blood sugar, say, before your meal or two hours after your meal. . . would be very helpful, because that's another thing I get amnesia on, is forgetting about [when to take blood sugar readings]. A beep would help me, but being at work. . . I'll turn my phone on silent—a vibration would be helpful just to remind you."

[P2]

"Maybe if I could leave the features I don't use [in this menstrual cycle tracker] behind, since I'm not trying to get pregnant, so just get rid of these fertile days."

[P4]

"[Receiving benefits for sharing migraine management tips with other app users] would be amazing . . . if I could have just pressed a button and sent it in [my migraine action plan from the app to the doctor's email], that would have been ideal."

[P5]

The aforementioned limitation about fitness-tracking apps not recognizing certain activities was also mentioned by another participant, who suggested:

> *"I guess being able to track different styles of exercise, so not just running and cardio-based activities, but if it could somehow track better movement with the bodyweight exercises or high-intensity exercises, which aren't as cardio-based."*
> [P3]

Furthermore, the same participant [P3] gravitated towards more interconnectivity of raw data from Medicare and data from multiple apps aggregated in one graph. Suggestions for improvement included appropriate use of gamification techniques throughout the app.

Discussion

Principal Findings

Data from this limited sample of health app users suggest self-management by health consumers with chronic conditions can be enhanced via use of mobile applications. This is the first-known research to combine these models, benefits of which include chronic condition-specific dimensions such as targeting health and information technology literacy, as well as functionality, engagement and information management. Additionally, more depth identifying usability issues when exploring consumer interaction with self-management goals via health apps was encountered when combining these three models. While the TAM and HITAM were not developed specifically for mobile apps, combining it with the MARS enabled a targeted, mobile health app focus and backing from more established technology acceptance constructs. Combining the TAM and HITAM with the more-recently-published MARS also provides an updated framework to assess health app usability. As confirmed by one study, health behavior is too complex and multi-faceted for one model to cover comprehensively,[39] which is why relevant constructs from TAM, HITAM and MARS were combined.

Similar qualitative studies include user perception of an oral health app.[59] However, user responses in that study were gathered via an online survey with no follow-up questions. Another health app study measured spirometry readings from adolescents with asthma and had no qualitative component.[60] This is the first study to explore self-care consumer experiences with health apps amongst adults. Our study covers a broader range of health apps, and more depth in exploring consumers' experiences.

Randomised-controlled trials have reported clinical impact of health apps on outcomes such as self-efficacy, but have not focused on consumer interaction and engagement. No controlled trials have been published exploring consumer engagement with health apps. Adopting a qualitative approach has enabled insight into consumers' experiences with health apps across a range of health conditions and with sufficient depth to understand motivators, desired features and issues relating to persistence.

The MARS was designed to provide quality star ratings for health apps.[43] This research has aligned the 'Engagement' theme from the MARS in the context of health apps. 'Functionality', concerning the operability of apps, is aligned with the MARS and HITAM, the HITAM introducing concepts such as health beliefs. 'Information Management' was aligned from the HITAM, while 'Ease of Use' was aligned from the TAM and relates to personalization of the user experience. This research provides novel insight from combined models to describe the experiences of users of health apps. User experience design considers user experience, including usability and perceived enjoyment of the product.[33, 61]

This study has established that self-management of a chronic condition using an app requires constant stimulation to accommodate changing user requirements and changes in wellbeing. Additionally, this study determined consumers with chronic conditions such as diabetes, depression, weight and sleep management issues are often recommended fitness apps. There were participants with a chronic condition who only used a fitness app and no disease-specific app. During the interview, no participant expressed confusion using an app to the point additional training or information such as on YouTube® was required.

The benefits of gamification in health apps have been reported,[23, 62] but there has been only one chronic disease clinical trial using gamification, amongst minors.[60] Gamification in a health context does not necessarily 'trivialize' health management.[23] However, gamification involving inter-personal competition would be most suited to fitness trackers, whilst gamification for health apps would be most suited to intra-personal competition. Some apps were identified by participants as incorporating elements of gamification,[62] and provided those participants dynamic opportunities to engage with their health apps, such as receiving badges, passing levels and animated learning.[23]

Some health apps are designed for novelty or entertainment purposes, such as those providing blood pressure readings via touching the screen;[63] the accuracy of such outputs for medical monitoring is questionable. All participants presented apps designed for the intended medical or health purpose. Research suggests a paucity of evidence-based apps.[43] Restricting our inclusion criteria to evidence-based apps would have been inefficient, since research in this area is regularly updated.

Apps used via smartwatches and mobile telephones should offer more convenience than those requiring a tablet device or personal computer. This was confirmed by the participant who presented with an Apple Watch® for convenient use of the health app of choice. As consumer uptake of smartwatches and other smart wearables increases, unique functionality with apps will emerge.

The present data cannot conclusively support the correlation between "willingness to pay" and "user experience", although the correlation has been reported elsewhere in a study of mobile apps.[61]

Actual health benefits from engagement with self-monitoring can only be determined through clinical trial of an app. Nevertheless, *perceived* benefits from self-documentation can improve a consumer's engagement with a health app, and provided the measurements are valid and reliable, this practice would presumably improve self-management. Positive oral hygiene self-management have been reported as a result of engagement with a health app.[16]

Some participants indicated their health professionals (dietician, psychologist or general practitioner) are already receiving consumers' self-reported data electronically. How health professionals use these data requires further investigation, specifically, whether they cross-check consumer-reported clinical readings with their own, or consider trends in consumer-reported data.

Participants tended to reduce usage of their app when they reached their goals and no new self-management techniques were offered. For app engagement to be sustained after reaching a goal or for usage to become habitual, regular intervals of engagement are recommended. Rewards for chronic conditions involve intra-personal competition and involve different metrics to fitness apps employing more persistent and active inter-personal competition. Fitness apps can be used by consumers with chronic conditions such as diabetes and depression as part of a self-management program. At present, there is no research exemplifying long-term impact of reward-based engagement for mobile health apps.

Health monitoring devices are steadily increasing in market availability, with biometric-based innovations reducing the need for manual data input by consumers and providing more advanced, ubiquitous features.[25] Partnerships between health researchers and start-up communities, known for their agile coding methods, could help develop health apps conformant with the themes identified in this research: Engagement, Functionality, Information Management and Ease of Use.

Strengths and Limitations

As explained previously, strengths of this study include combining the TAM, HITAM and MARS in a single study, which has not been attempted before, providing greater breadth in the deductive analytical framework than with the use of a single model. Additionally, using the post-positivism paradigm supports the concept of ever-changing consumer user requirements by viewing "knowledge as conjectural."[64]

Limitations in this study include not referring participants to suitable apps based on their insight, and not scheduling a follow-up interview to gauge a change in their user experience. As such, these data represent a point-in-time measurement, and longitudinal research would better gauge individuals' changes in self-monitoring patterns. This study was limited to a predominantly tertiary-educated Australian perspective; apps marketed internationally may incorporate different user experience metrics. This study did not quantify participants' experiences, which would be of greater use and relevance when a single app is studied. It is unknown whether male and female users of health apps differ in their usage and expectations of these apps. The present sample comprised mostly female participants, possibly due to the recruitment methods.

This study is unable to correlate user experiences with credibility of health app. It may be possible for users to report positive experiences with an app that lacks an evidence base; conversely, an evidence-based app might be poorly designed, with low levels of engagement or usability. There are minimum design guidelines for the Apple App Store®[65] and similar guidelines for Google's Play Store®,[66] although these were not assessed in our study.

Our research has revealed a range of apps used by consumers with a particular health condition, and use of multiple health apps. It would not be feasible to focus the study on one app; this would also limit the generalizability of the findings.

This study deliberately included a broad range of users of a variety of health apps, and it is not feasible to draw correlations or associations between groups of participants. Because some consumers used more than one app to manage their condition, any attempt to document the outcomes from use of a particular app could be confounded, and would rely on self-report. Evaluation of the clinical contribution of apps to health care requires careful experimental design and control of environmental influences on self-management of the medical condition of interest.

Participants discussed the app with which they are most familiar (most engaged), as this would highlight any frustrations they had encountered with programming bugs and limitations. However, participants were welcome to discuss other health/fitness apps with which they had experience. In the interests of keeping participants engaged in the interview, and ensuring currency and validity of the data, it was not considered worthwhile for participants to discuss all health/fitness apps they recalled using.

Further Research

Future research may focus on users of apps for a particular health condition (e.g. asthma), with longitudinal monitoring of their engagement with a selected app(s) and changes in user experiences. Usage of apps incorporating gamification is an area requiring supplementary research, to enable researchers to gauge whether artificial intelligence has been designed in an intuitive and compatible way with regard to consumers' health objectives.

The concept of competitive wellbeing also warrants consideration, with social Application Programming Interfaces linking health data to social media and other services to increase motivation and competitive spirit, and to assist users to achieve health goals.[67] Chronic conditions require persistent self-management and longitudinal monitoring, and health apps should deliver a customized solution for the user's condition.[68] Moreover, sustained use of apps can be optimised by further insights into how consumers use apps.[69]

Conclusion

This study explored consumers' interactions with health apps through semi-structured interviews, uncovering a wide variety of users with a degree of commonality in their user experiences. User experiences have been described via four themes: Engagement, Functionality, Information Management and Ease of Use. These themes describe concepts such as motivation, customization, interconnectivity, data inaccuracy, convenience and competitiveness, and suggest how health apps can benefit by 'growing' with the user and adapting to changing operating environments.

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Author Contributions

Conceived and designed the experiments: KA LE OB. Performed the experiments: KA. Analyzed the data: KA LE OB. Wrote the paper: KA LE OB.

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3 CHAPTER 3: Evaluation of Apps for a particular Health Condition

3.1 Preface

This chapter comprises a published protocol, with results of the protocol applied to a chronic condition and further validated with another chronic condition, both of prevalence in Australia. Objectives 2a and 2b are addressed in this chapter, namely “Synthesis of a usability checklist (for health app quality)” and “Creation of a protocol to replicate findings to assess a range of commercially-available apps.” Subsequent to the publication, minor functional changes were required during the iterative process of evaluating health apps; these are described later.

The protocol described in this chapter comprises a shortlisting and screening process for apps only, rather than any associated wearables or measurement devices.

3.2 JMIR Manuscript: Synthesis of a Protocol

This sub-section presents the *JMIR* protocol manuscript as it was accepted for publication on 4 November 2016. The resulting checklist (the ACDC) is available in Appendix 6: ACDC (*JMIR* Appendix), in addition to Appendix 7: ACDC Instructions for Raters (*JMIR* Appendix). Permission to use an Australian-approved peak flow chart is provided in Appendix 8: Peak Flow Chart Consent Form.

The concept of utilising theory to guide a development process is strongly recommended and it supported in health technology research.[98] Additionally, the ACDC, through the nature of a protocol, specifies the “intervening steps and processes” and provides an opportunity for feasibility testing by third parties.[98]

It is important to note a clinician recommending an app to a consumer provides the consumer with freedom to explore the app that the clinician thinks is fit for purpose which is not the purpose of the ACDC. However, identifying a good app to use in a clinical trial via the ACDC implies the clinician requires to familiarise with the app and how the data can be downloaded and managed for the trial.

Protocol

App Chronic Disease Checklist: Protocol to Evaluate Mobile Apps for Chronic Disease Self-Management

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Abstract

Background: The availability of mobile health apps for self-care continues to increase. While little evidence of their clinical impact has been published, there is general agreement among health authorities and authors that consumers' use of health apps assist in self-management and potentially clinical decision making. A consumer's sustained engagement with a health app is dependent on the usability and functionality of the app. While numerous studies have attempted to evaluate health apps, there is a paucity of published methods that adequately recognize client experiences in the academic evaluation of apps for chronic conditions.

Objective: This paper reports (1) a protocol to shortlist health apps for academic evaluation, (2) synthesis of a checklist to screen health apps for quality and reliability, and (3) a proposed method to theoretically evaluate usability of health apps, with a view towards identifying one or more apps suitable for clinical assessment.

Methods: A Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram was developed to guide the selection of the apps to be assessed. The screening checklist was thematically synthesized with reference to recurring constructs in published checklists and related materials for the assessment of health apps. The checklist was evaluated by the authors for face and construct validity. The proposed method for evaluation of health apps required the design of procedures for raters of apps, dummy data entry to test the apps, and analysis of raters' scores.

Results: The PRISMA flow diagram comprises 5 steps: filtering of duplicate apps; eliminating non-English apps; removing apps requiring purchase, filtering apps not updated within the past year; and separation of apps into their core functionality. The screening checklist to evaluate the selected apps was named the App Chronic Disease Checklist, and comprises 4 sections with 6 questions in each section. The validity check verified classification of, and ambiguity in, wording of questions within constructs. The proposed method to evaluate shortlisted and downloaded apps comprises instructions to attempt set-up of a dummy user profile, and dummy data entry to represent in-range and out-of-range clinical measures simulating a range of user behaviors. A minimum score of 80% by consensus (using the Intraclass Correlation Coefficient) between raters is proposed to identify apps suitable for clinical trials.

Conclusions: The flow diagram allows researchers to shortlist health apps that are potentially suitable for formal evaluation. The evaluation checklist enables quantitative comparison of shortlisted apps based on constructs reported in the literature. The use of multiple raters, and comparison of their scores, is proposed to manage inherent subjectivity in assessing user experiences. Initial trial of the combined protocol is planned for apps pertaining to the self-monitoring of asthma; these results will be reported elsewhere.

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KEYWORDS

health; mobile applications; app; smartphones; self-management; protocol; usability checklist; self-care; chronic disease

Introduction

Management of chronic conditions has evolved from traditional paper-based monitoring and action plans [1] to the use of mobile messaging [2], and now smartphone and other mobile apps to record and manage clinical data [3-5]. One such application of this technology involved a self-care app for salt intake, which has a protocol published for its use [6]. Although such apps are widely supported by health authorities and authors to enhance consumers' engagement with self-management, more long-term randomized controlled trials (RCTs) are required to measure their clinical effectiveness and frequency of use [7,8]. Additionally, self-care guidelines should be updated to incorporate engagement with mobile apps during RCTs [9].

Selecting a health app to facilitate self-care of a chronic condition can be overwhelming due to the increasing number of apps for a wide range of health conditions. Engagement with a health app lacking essential operational features, storage and calculation of clinical measures, and unaligned to the consumers' requirements, can result in declined usage of the app, potentially compromising self-care regimens [10].

Furthermore, many health apps lack a theoretical foundation, as identified in a news post by an emergency room doctor and medical professor in North Carolina [11]. Some apps are structured with a clinical appearance and facilitate data entry by consumers, but are created for entertainment purposes, as acknowledged by another journalist based on the same doctor's findings [12]. Additionally, consumers' decisions to select apps presented in the Apple App Store and the Google Play Store are clouded by marketing jargon and lay-user reviews, with an absence of official and consistent quality markers [13].

The certification of health apps to improve safety and quality in health care is an ongoing issue [14]; theory-based quality ranking of apps has begun [15] but is in an early stage. Proposed interventions include active review of every health app by app stores and/or regulators such as the Food and Drugs Administration (FDA) in the United States or the Therapeutic Goods Administration (TGA) in Australia [14]. This method is expected to be relatively slow and costly. Complicating this problem, many health apps do not fall within the jurisdiction of the FDA [5], TGA, or their overseas counterparts, particularly if the apps are not classified as medical devices and have no peripheral device requiring regulatory assessment. Consequently, the need for further research into the clinical integrity of health apps is warranted.

A recently published initiative using a rating scale for health apps named the Mobile Application Rating Scale (MARS) [16] was produced in Australia, and designed to aid app selection by researchers. The MARS appears comprehensive when rating mental health and general health apps, but has not been specifically designed for chronic conditions. Additionally, the 23 sub-categories of the MARS were not all grounded in health consumer mobile app experiences; some usability studies informing the MARS included health website evaluation [17], nonhealth website quality measurement [18,19], user experiences with online goods [20], and nonhealth-specific evaluation frameworks [21]. One recent study questioned the MARS' validity, since it has not been widely adopted [22]. However, building or updating an app to rate against the MARS requires due process, and more findings are expected since an Australian state government healthy body endorsed the scale, attracting media attention [23].

A number of other studies regarding the usability of health apps have reported findings [24-26], a content analysis guide [27], a mobile website framework [28], and an app design and development guideline [9]. One app-usability study [28] built upon Nielsen's usability heuristics [29], but was not health-tailored. Table 1 outlines health app usability studies that have produced checklists or rating scales; these are critiqued later in this paper. Growth in the health app market, both in terms of availability and adoption, warrants greater distinction between apps. A need exists for a protocol to guide researchers in their identification of apps suitable for assessment, and for developers to test their product against competitors' apps. This paper reports (1) a protocol to identify relevant apps for academic evaluation, (2) synthesis of a checklist to screen apps for quality and reliability, and (3) a proposed method to theoretically evaluate the usability of health apps, with a view towards identifying one or more apps that are suitable for clinical assessment.

Table 1. Commonalities and differences between health app usability studies.

Authors	Year	Name of rating scale or checklist	Purpose	Consumer vs academic use	Number of dimensions	Number of raters
Stoyanov et al [16]	2015	Rating scale[a]: Mobile Application Rating Scale (MARS)	Quality assessment	Academic	5	2
Nielsen [29]	1994	Checklist[b]: Nielsen's Usability Heuristics	Rectify usability problems	Academic	10	3-5
Hundert et al [5]	2014	Checklist: 7 criteria	Headache diary app evaluation (scored against 7 criteria)	Both help to inform health care professionals and potential users on the best available e-diary apps for headaches	7	2
Belmon et al [30]	2015	Rating scale: for app features, not complete apps; Behavior Change Techniques (BCT)	Young adults' opinion on BCT in physical activity apps	Consumer rating	3	N/A (179 young Dutch adults)
Patel et al [15]	2015	Rating scale: MARS [16]; (1) Weight loss/smoking cessation criterion score, (2) cultural appropriateness criterion score, and (3) cultural appropriateness criteria	Quality ranking	Academic	3 with 22, 23, and 6 subcriteria, respectively	2
Yanez Gomez et al [31]	2014	Mobile-specific usability heuristic checklist	Heuristic evaluation	Academic	13	As per Nielsen [29]

[a]A rating scale's results align a numerical value to constructs such as *Ease of Use*.

[b]A checklist can be a series of requirements necessary to achieve compliance without numerical values.

Methods

Phase 1: Development of an App Selection Protocol

Selection of relevant apps (and elimination of irrelevant apps) requires sequential consideration of the publicized and evident features of apps. A Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram was deemed suitable for representation of the shortlisting process. In the absence of guidance from published literature, critical decisions for the purposes of shortlisting health apps were based on:

Relevance: limiting searches to the respective country's app stores ensures relevance to the local setting. Duplicate apps require removal from the shortlist. Preliminary trial of the PRISMA flow diagram has identified some apps available on both iOS and Android operating systems with similar names, requiring further examination of app logos and *screen dumps* available from the respective app store. Cases in which both an Apple and Android version of an app are available result in the Apple version being recommended to be retained, since health apps with clinical management in Australia are launched on iOS first (Brophy S, personal communication, 1 January 2015).

Availability in English: this enables evaluation of the app in the local environment. Preliminary trial of the selection process has indicated that some apps displayed in a language other than English are also available in English once the app has been downloaded.

Provision of clinical management: preliminary trial of the flow diagram suggests health apps can be classified into 5 categories. *Clinical management apps* require the user to input clinical readings such as peak expiratory flow (for asthma monitoring) or blood pressure (for hypertension monitoring), and may integrate gamification for sustained usage of the app. *Informational apps* or *eBooks* are simply digitized books containing information about a condition, without facilitating data input. *First aid apps*, ambulance apps or individual doctors' apps were classed as extraneous to the use of the app for self-monitoring of a medical condition. *Exercise or yoga apps* involve holistic management of the medical condition through techniques such as controlled breathing techniques or yoga poses. *Novelty apps* or apps for entertainment purposes include prank apps and games using fictional characters with the target condition. Certain apps, identified through searches restricted to Australia, are only available via an international account, and have been categorized accordingly.

Availability at no cost to consumers: if the purpose of the shortlisting and evaluating apps is to identify an app(s) suitable for formal evaluation via clinical trial, or as part of the outcome measures in a trial, ideally the app(s) should be available at no cost to consumers. This parameter assumes that the cost of an app is unrelated to quality of the app.

Currency: the date of the most recent update is a particularly important eligibility criterion, since it represents the frequency with which developers respond to consumer feedback.

Phase 2: Development of the Evaluation Checklist

The app evaluation checklist was synthesized using peer-reviewed checklists and studies on the usability of health apps [5,15,16,25,27,29-35], supplemented with a qualitative study exploring consumer experiences with health apps [10]. Critique and comparison of the extant checklists, and the proposed checklist, are presented in the *Results* section. Criteria-based quality assessment was applied by creating the checklist in a number of iterations, data reduction [36,37], and assessment of face and construct validity by the authors. Face validity involved reviewing syntax and structure of checklist questions to ensure that questions reflect the research objectives. Construct validity required testing the definition of themes; these discrepancies were verified using definitions provided by similar studies, and cross-referenced with theoretical models.

This checklist was also created with reference to the principles of heuristic evaluation [29,38], which encompasses the construction of small but broad *usability principles* to evaluate an app's usability [29]. Heuristic evaluation has been applied successfully in the development of a number of health apps, such as headache diaries [5] and healthy eating apps [39], to guide design features such as the maximum number of items to maintain comprehensiveness, specificity, and efficiency. Nielsen's Usability Heuristics [29] were the foundation of several mobile app usability studies [5,28,31], and were applied here. The checklist was designed to enable rating by assessors, as per another Australian health app study [16]. For efficiency and to avoid transcription errors, the checklist should be created with survey software such as Qualtrics, rather than in hard copy.

Heuristic evaluation involved the application of 10 principles to each app, as reported by the Oracle Corporation [38]:

1. Visibility of system feedback: can the system show the user what part of the system is being accessed? Does the *back* button inform the user where they are returning to?

2. Complexity of the application: is the information technology and health literacy displayed in the app applicable to the target audience?

3. Task navigation and user controls: is the shortest possible path taken for users to perform tasks?

4. Consistency and standards: are industry standards adhered to, so users are not confused about the meaning of certain standards (eg, metric units) or conventions?

5. Error prevention and correction: are users prevented from making errors, such as entering letters in a numbers field?

6. Recognition rather than memory overload: does the system help people remember, rather than presenting all information at once?

7. Efficient to use: is there a basic and advanced mode to cater to different users?

8. Simplicity and appeal: is the system and design easy to use/appealing?

9. Be tolerant and reduce cost of errors: do errors provide avenues for further support? Can users move on after an error?

10. Help support: are there helpful suggestions for users to follow when unsure how to proceed?

Phase 3: Development of the Method to Evaluate the Usability of Health Apps

In order to apply the evaluation checklist to selected apps, a number of procedures are required: (1) determination of the number of independent raters; (2) moderation of differences between raters; (3) instructions for set-up and simulated use of the app, such as identification of a realistic user profile for all raters to enter; (4) standardization of time for initial navigation of the app; and (5) particular tasks to attempt to represent a range of user behaviors, and test the limits of the app. A simple summative scoring system is suggested to identify those apps considered to have met the criteria for formal evaluation or inclusion in a clinical trial. The scores of multiple expert raters should be compared using the 2-way mixed Intraclass Correlation Coefficient (ICC), since the same raters rate shortlisted apps using the same checklist. Consideration of interrater reliability using the ICC with SPSS version 23 (IBM Corp., Armonk, NY; 2015) is used. Utilization of the ICC is recommended to capture the varying *magnitudes of disagreement* [5] present in subjective usability metrics, and to measure homogeneity amongst raters. Internal consistency should be assessed using Cronbach alpha to ensure questions used in each section of the questionnaire are measuring the same construct [5,40]. Instructions for management of these calculations are presented in the *Results* section.

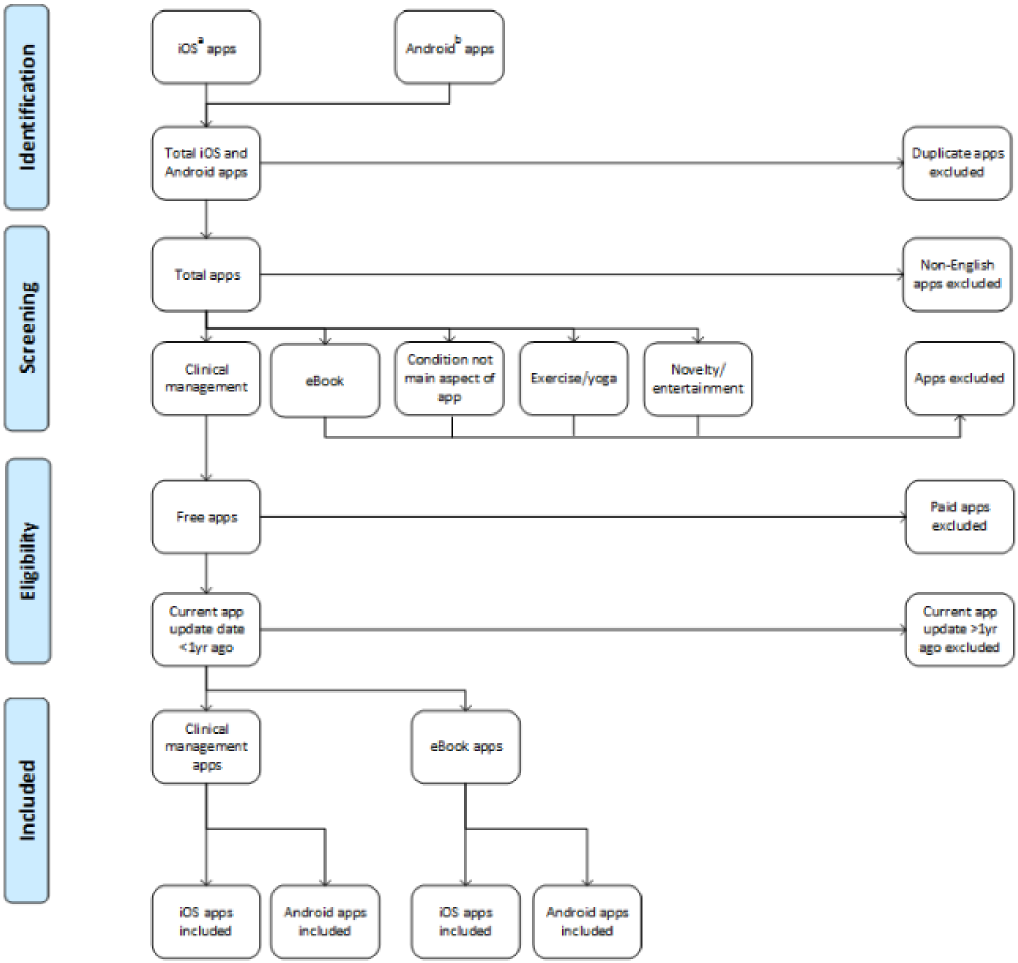
Results

Phase 1: Development of an App Selection Protocol

The process for filtering health apps available from the Australian Apple App Store and the Google Play Store to meet selection criteria is represented in Figure 1. In line with the 5 critical decisions described in the *Methods*, the flow diagram assesses relevance, English language, clinical management, free availability, and currency of the version.

This app-identification procedure uses the Australian Apple App Store and Google Play Store to locate apps specific to the target chronic condition. Subsequently, duplicate apps are removed, in addition to foreign language apps with no English language option. Apps not providing clinical management of the target condition are removed. Only free apps that have been updated less than 1 year ago are retained.

Figure 1. PRISMA flow diagram. [a]Via Australian iOS APP Store (iTunes), [b]Via play.google.com (Australian account).



Phase 2: Development of the Evaluation Checklist

In total, 6 peer-reviewed checklists focusing on usability of health apps were identified [5,15,16,29-31], as presented in Table 1. The MARS comprises 4 dimensions, totaling 19 items, with another subjective quality and app-specific category of 10 items [16]. Dimensions used in the 6 studies ranged from 3 to 13. Overall, there were consistent themes in the extant checklists, but subcomponents (ie, warnings about unhealthy values, user profile setup, and features available in offline mode) were lacking.

In addition to the studies described in Table 1, 1 app usability framework for health websites provided useful insight into theory underlying the Technology Acceptance Model (TAM) and user experience [28]. Another study [41] was not health related, but guided creation of the checklist, with reference to some common considerations regarding app usability, such as design and *help* features. Self-care guidelines when using an app were also instrumental in guiding the design of this protocol, although no rating scale or checklist were evident [9]. One content analysis guide for smoking apps [27] confirmed findings from the aforementioned studies including feedback, app content, user relevance, and user experience.

Other peer-reviewed studies have reported health app usability research without applying checklists, rating scales, guidelines, or frameworks. A New Zealand ranking system for weight loss and smoking cessation apps used 22 and 23 items respectively, considering social networking synchronization, daily activities (eg, record of food intake), personalized feedback and engagement, and using a Boolean operator to award points for scoring purposes [15]. The items listed in this New Zealand study were specific to the health condition, rather than considering other factors affecting app quality. Additionally, 2 studies presented methods to select the most popular apps to rate [15,27], rather than create a checklist or rating scale for comparative assessment of apps. Comparing and contrasting the aforementioned checklists confirmed the need for the design process to consider how consumers maintain self-care practices.

Table 2 lists the constructs, variables, and source(s) of each variable in the resultant checklist, named the App Chronic Disease Checklist (ACDC); the complete checklist is illustrated in Multimedia Appendix 1. In total, 4 constructs (*Engagement*, *Functionality*, *Ease of Use*, and *Information Management*), derived from thematic analyses of published checklists and qualitative research, are represented in the checklist. A qualitative study [10] informed the need to include *Ease of Use* as a construct (rather than *Aesthetics*, a theme from the MARS), and broaden the scope of the *Information Management* construct.

Table 2. Thematic synthesis of the ACDC checklist.

Construct	Variable	Source
Engagement	Gamification	[10,15,42]
	Customization	[10,16,33,43]
	Interactivity	[10,16]
	Positive Behavior Change	[10]
	Effectiveness	[16]
	Self-Awareness	[10,16,30]
Functionality	Health Warning	[10]
	Feedback	[10,16,27,29,31,34,39,44]
	Intuitive Design	[10,16,33,34]
	Connection to Services	[10,16,24]
	Performance Power	[10,16,29]
	Structural Navigation	[16,29,31]
Ease of Use	Usability	[10,16]
	Automation	[10,26]
	Medical and Technological Jargon	[10,39]
	User Profile Setup	[10]
	Offline Mode	[10]
	Reminders	[5]
Information Management	Statistics	[5,10]
	Privacy and Data Security	[10,43-46]
	Quality and Accuracy of Information	[10,29,34,39,46]
	Quantity of Information	[16,39]
	Visual Information	[10,16]
	Credibility	[16]

Face and construct validity were confirmed via discussion amongst the 3 authors. Construct validity guided the classification of, and ambiguity in, wording of questions within constructs, as guided by the TAM [47] and Health Information TAM [48]. The TAM confirmed alignment of questions relating to *Reminders* and *Automation* within the *Ease of Use* construct. This process was undertaken simultaneously with the consideration of usability heuristics. Lack of information in studies considering *Visual Appeal*, for example, was addressed by using Nielsen's Usability Heuristics [29] and integrated into the *Functionality: Feedback* and *Information Management: Visual Information* questions. Discussion amongst authors and consideration of extant checklists determined that a 3-point ordinal scale, appropriately worded for each question, would be used. Details of this scoring scale are described later in this paper.

Phase 3: Development of the Method to Evaluate the Usability of Health Apps

The evaluation should be completed as soon as possible after shortlisting of apps, to ensure version control and currency. In two studies, 2 raters were used to apply scores to apps [5,16], while 1 study used 5 raters to measure usability [9]. This approach was consistent with the recommendation by Nielsen [29] to use 3 to 5 experts. In line with these recommendations, and a number of other health app studies [5,16,41], this protocol suggests 3 expert raters with no experience or conflicts of interest with any of the apps.

All clinical management apps retained by the flow diagram should be rated without collusion between raters, and in their entirety, before proceeding to a subsequent app. Initially, a sample (approximately 10%) of these apps should be randomly identified using a randomization algorithm, and quarantined for trial scoring by all raters, with results being moderated between the raters. Scores from this trial may be merged into the full scoring exercise if no significant changes have been made to the scoring protocol, as recommended by methodologists [40]. If a trialed app and a nontrialed app produce the 2 top scores, both scores should be moderated to identify the top-ranked app.

After proceeding with the assessment of the remaining shortlisted apps, raters' scores (saved in the online survey platform) will be imported to SPSS for calculation of usability scores and interrater and internal reliability. Each response on the 3-point ordinal scale will be assigned a value of 0 (where the feature is not evident or functional), 0.5 (where the feature is somewhat evident or functional), or 1 point (where the feature is clearly evident or functional), and summed to a total (out of 6) for each of the 4 constructs, as well as a total out of 24 for each app.

As established in the *Methods*, 2-way mixed ICC is recommended to measure interrater reliability [49]. The ICC should be calculated for the total score (out of 24) to compare the 3 raters, and the raters' totals for each construct: *Engagement*, *Functionality*, *Ease of Use*, and *Information Management*. Differences in scores should only warrant moderation if the ICC for each construct is nonsignificant ($P>.05$). Subjective questions, such as those within the *Ease of Use* construct, are expected to generate a lower ICC score in that construct, compared to more objective ratings of items relating to *Privacy* or *Ability to Export Data*.

One Cronbach alpha statistic should be calculated to measure correlation between the collective totals for each construct (out of 18 for each construct, if using 3 raters). Cronbach alpha should also be determined for the total score (out of 72) for the 3 raters collectively.

Before the apps are set up, instructions commence by entering all remaining shortlisted apps into a random list generator. The purpose of randomizing apps is to eliminate selection bias by balancing *unknown factors* [50]. Apple HealthKit apps actively monitor consumer readings, so raters should create unique logins that are clearly identified as being associated with trial of the app (eg, a consumer name such as *Test Dummy 1*); however, raters should provide authentic contact details for compulsory profile fields to facilitate receipt of outputs, if this is a function of the app. If raters encounter requests for additional data, the recommended approach is to refer to the Instructions for Raters (Multimedia Appendix 2).

Figure 2 illustrates the features of a dummy profile for entering clinical data into shortlisted apps to gauge the app's usability and functionality. The dummy profile comprises a range of realistic goals, and demographic and clinical data that reflect information that might be requested of new users. These data should be adjusted by the lead investigator to be realistic for the medical condition of interest (eg, obesity management).

As part of the dummy profile, raters should attempt to enter 1 week of realistic in-range clinical readings, taken with good compliance, with the recommended self-monitoring schedule for the relevant medical condition. This week should be followed by 1 week of readings representing poor control of the medical condition, with several days of poor compliance with self-monitoring. An example based on peak expiratory flow readings (for asthma monitoring) is provided in Figure 3, in which an adverse event such as a respiratory infection (in red) has affected a consumer's readings, and numerous readings are missing during this period of out-of-range data. Such variations in clinical data are important to gauge how the clinical management app responds to variable control of one's chronic condition and inconsistency in data entry. If raters encounter requests for additional data, the recommended approach is to discuss a course of action with other raters before proceeding.

Figure 2. Test dummy profile for clinical data entry.

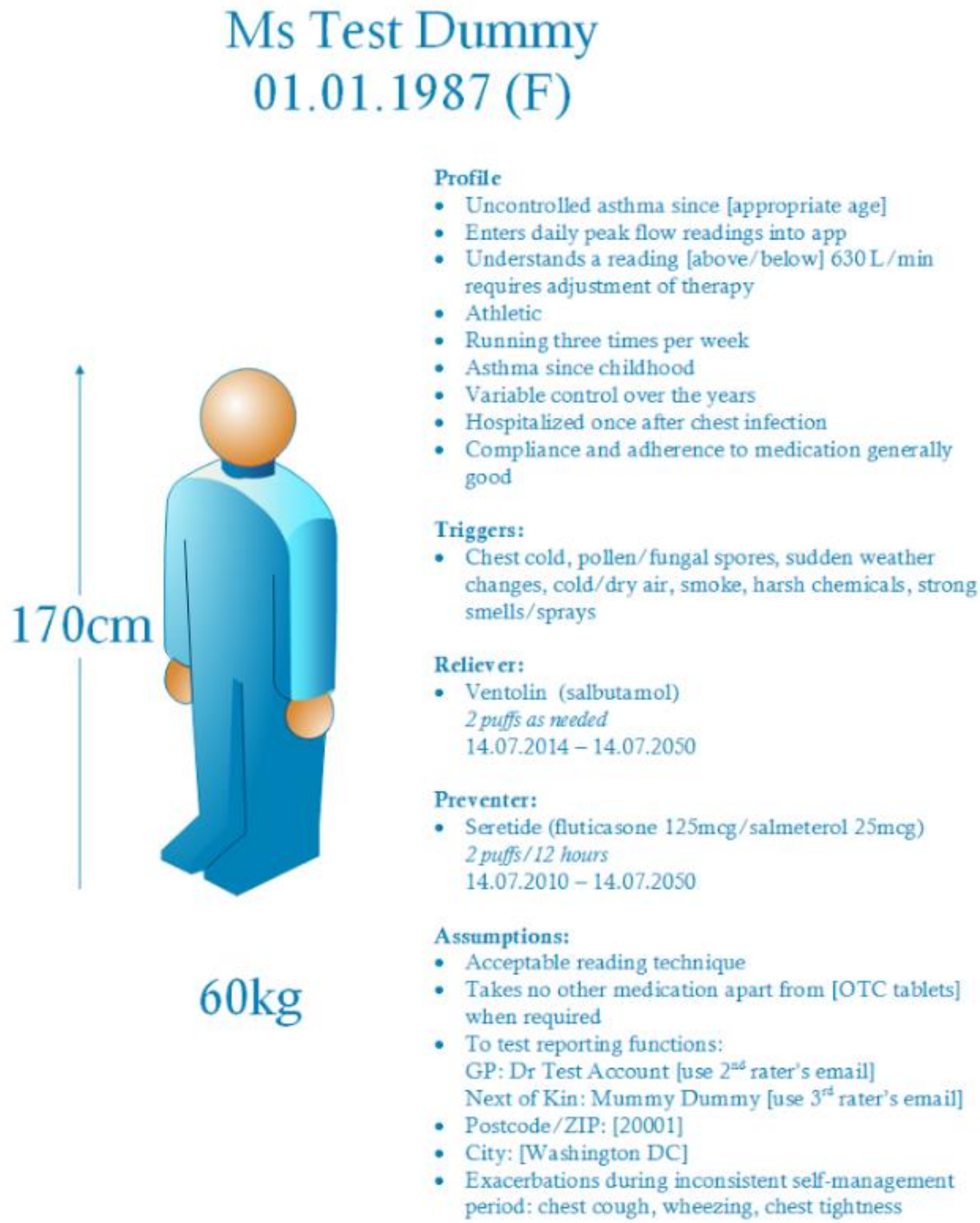
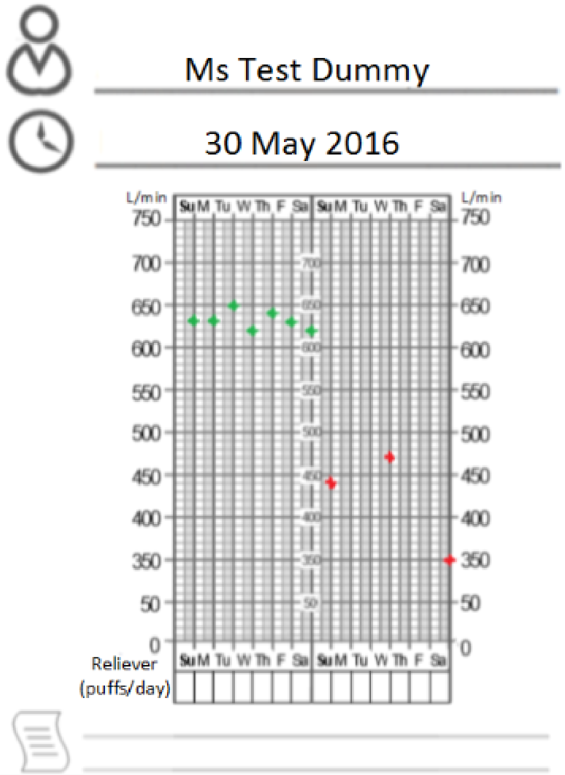


Figure 3. Peak flow values to input into shortlisted clinical management apps.



Adapted with permission from:
Woolcock Institute of Medical Research, 2006
Reddel HK, Vincent SD, Civitico J. The need for standardisation of peak flow charts. Thorax 2005; 60: 146-7.

Discussion

Creating a health app selection protocol for developers and academics resulted in a guided and evidence-based procedure that aims to guide researchers to identify a health app with the highest level of usability and functionality characteristics. The identified app may then be the subject of a clinical trial as an independent intervention in health consumers' self-management of a chronic condition, or as an adjunct for other interventions. The need for evidence-based content when deciding which health app to use is also supported by a 2016 Australian review of mental health apps [51]. Consequently, consumers using top-ranking apps identified by this protocol are expected to demonstrate greater persistence with self-management of medical conditions. This theory, however, remains to be tested.

Dissemination of this protocol should also benefit app developers in their appreciation of usability heuristics and features of highly-functional, high-quality, and attractive apps. Future variations could include a developer-specific checklist, with design science and computer science-related constructs aiding the app design and development process.

The key contribution of this protocol to the body of research in this field lies in its comprehensiveness. This protocol incorporates a 3-stage method to shortlist apps, and then assesses the shortlisted apps using standardized instructions for a team of raters using an evidence-based checklist (the ACDC). The use of 3 expert raters is expected to be economical, without compromising robustness; trial of the protocol and determination of the interrater reliability statistics are required to confirm this theory.

While a previous study reported a brief flow diagram for the selection of an app [16], the inclusion of more selection criteria in the flow diagram enables more discriminatory filtering of available apps. The number of apps retained by this filtering process is expected to vary according to the chronic condition and number of marketed apps. Additional shortlisting criteria may be included if the final number retained apps remains unmanageable.

The ACDC draws most heavily on the MARS [16], with a number of differences informed from the review of other literature, and recognizes that findings from the MARS have not yet been published. First, *Ease of Use* has been identified as a construct in the ACDC, rather than *Aesthetics* (in the MARS). This development was informed by qualitative research [10] that reported strong consumer sentiment in health app experiences. By including this consumer perspective, the ACDC recognizes the importance of a consumer's persistence with a health app for self-management of a chronic condition [10,52,53]. Second, the *Information Management* construct has been broadened in the ACDC to reflect data concerns in the information age, as informed by qualitative research [10]. Third, the ACDC was designed for use in apps for any chronic condition, not just mental health, which is the reported use for the MARS [16]. Fourth, a limitation of the MARS identified in the *Introduction* was the MARS's construction with reference to sources beyond health app usability studies. The ACDC was constructed via thematic synthesis from a body of literature specific to health app usability.

Apps are being launched with increasing frequency, and considering the ubiquitous nature of smartphones and electronic health strategies of hospitals and clinics, the use of health apps to facilitate self-care of chronic conditions will continue to expand. The authors acknowledge the release of Apple's ResearchKit [54] and the more individualized CareKit [55], which harbor the ability of researchers to embed surveys in Apple apps for data reporting. Android-based smartphones will soon have access to these open-source Apple apps (eg, Asthma Health [56]) that are available for American Apple account holders only. In the future, authors of clinical outcome questionnaires should enable researchers to integrate questions into platforms such as ResearchKit, for efficiency and convenience of data entry during clinical trials.

It is essential for developers and academics to employ a profile with dummy values to test the shortlisted apps, with the profile including compliant and noncompliant clinical readings, in addition to registering a real email account to which readings can be exported. One limitation of this approach is that a single dummy profile, even devised with in-range and out-of-range clinical data, is unlikely to test the full functionality of an app. However, a carefully constructed dummy profile and the use of 3 raters, each completing a 24-question assessment of the app, should enable thorough evaluation and ranking of the shortlisted apps.

This protocol offers a comprehensive procedure and straightforward checklist to guide selection of highly-functional and usable health apps for use in further research, or self-management by consumers. To date, the protocol has been partially tested; the first research study will apply this protocol to apps for asthma self-management.

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Conflicts of Interest

None declared.

Multimedia Appendix 1

App Chronic Disease Checklist v1.0.

[PDF File (Adobe PDF File), 38KB - resprot_v5i4e204_app1.pdf]

Multimedia Appendix 2

Instructions for raters.

[PDF File (Adobe PDF File), 39KB - resprot_v5i4e204_app2.pdf]

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Abbreviations

ACDC: App Chronic Disease Checklist

BCT: Behavior Change Technique
FDA: Food and Drugs Administration
ICC: Intraclass Correlation Coefficient
MARS: Mobile Application Rating Scale
PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RCT: randomized controlled trial
TAM: Technology Acceptance Model
TGA: Therapeutic Goods Administration

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3.3 Further Literature Searches

To date, and as recognised in the paper on preceding pages, the most recognised health app checklist published and used as the foundation for the ACDC has been the MARS. An updated literature search was conducted using MEDLINE, Cochrane Library, ProQuest and Global Health (Ovid) databases spanning the period June 2015 to February 2017, with keywords and authors' names, to identify studies in which MARS had been applied or critiqued since its publication.

To ensure comprehensive coverage of the recent literature in this field, a broader search was also conducted using the same databases, supplemented with searches within *JMIR* and *PLOS ONE*, spanning January 2016 to January 2018, to identify any other recently-published novel scoring instruments for similar purposes. *JMIR* is a discipline-leading journal, publishing the majority of peer-reviewed health app studies among its various titles. *PLOS ONE* is a multi-disciplinary journal publishing a strong number of eHealth and mobile app studies. Search terms were:

> 'mobile app*' OR 'mobile phone' OR smartphone OR 'smart phone' OR 'mobile device', AND 'self-care' OR 'self-monitoring', AND hypertension OR 'blood pressure' OR cardiac OR heart OR depression OR anxiety OR mood OR diabetes OR pain OR asthma OR menstrual OR period OR smoking, AND checklist OR instrument OR 'rating scale' OR assess OR quality.

The medical condition search terms were included to represent those that are commonly self-monitored, and likely to be a focus of a trial leading to publication.

An environmental scan discovered Apple's open source ResearchKit framework. Given the investment and partnership with multiple American universities in building and testing health apps to a standard accepted by academics and hospitals alike, this would validate the ACDC for a broader range of health conditions.

Critique of the identified recent literature is located throughout the following sections.

3.4 Methodological Commentary

3.4.1 Introductory ACDC Commentary

The usability checklist was drafted during the qualitative data collection stage; however, the findings from its published manuscript[65] were required to finalise the checklist. It was envisaged no more than 20 items would be included in the checklist. Weighting of individual criteria were to be considered, as per a recent Australian study.[99]

Heuristic evaluation principles were encapsulated in the usability checklist. Heuristic evaluation involves the construction of small but broad "usability principles" to evaluate an app's usability.[100] Heuristic evaluation has been found successful for a number of health apps such as headache diaries[101] and healthy eating apps.[102] In the current study, heuristic evaluation was used by applying the following 10 (paraphrased) principles[103] to each app:

1. "Visibility of system feedback:" Can the system show the user what part of the system is being accessed? Does the 'back' button inform where the user is going back to?
2. "Complexity of the application:" is the IT and health literacy displayed in the app applicable to the target audience?
3. "Task navigation and user controls:" Is the shortest possible path taken for users to perform tasks?
4. "Consistency and standards:" Are industry standards adhered to so users are not confused about the meaning of certain standards (e.g. metric units) or conventions?
5. "Error prevention and correction:" Are situations prevented from errors such as letters in a numbers field?
6. "Recognition rather than memory overload:" Does the system help people remember rather than presenting all information at once?
7. "Efficiency of use:" Is there a basic and advanced mode to cater for different users?
8. "Simplicity and appeal:" Is the system and design easy to use/appealing?
9. "Tolerance and cost of errors:" Do errors provide avenues of further support? Can users move on after an error?

10. “Help Support:” Are there helpful suggestions for users to follow when unsure how to proceed?

Design of guidelines or checklists is highly dependent on the chronic condition in question. One paper divided design factors into “clients and therapists”[80] whilst considering factors relevant to the particular chronic condition. It is not just health and IT literacy to be considered when designing usability guidelines for health-related apps.

3.4.2 Supplementing a Checklist with Clinical Questionnaires

Since the development and trial of the ACDC, three studies have been published in which apps were rated using the MARS,[99] as outlined in Table 1. The conditions for which the apps had been produced were weight loss and smoking cessation,[104] heart failure[105] and mindfulness.[106]

Table 1: Application of the MARS to rate health apps

Author	Location	Condition(s)	Study Design e.g. RCT, protocol	Changes made to MARS or supplementary scales used	Critiques made to MARS and Key Findings
Masterson Creber et al., 2016 [105]	New York, America	Heart failure	Rating of 34 apps	No changes made to the MARS, but all 34 apps were also rated using: i) IMS Institute for Healthcare Informatics functionality scores ii) Heart Failure Society of America (HFSA) guidelines for non-pharmacological management of heart failure.	No critique provided
Patel et al., 2015[104]	Otago, New Zealand	Weight loss and smoking cessation	Scoring of 120 apps	MARS score comprised 45% of total score, supplemented by weight loss / smoking cessation criterion score (45%) + cultural appropriateness criterion score (10%)	◦ Literature informed further two scoring sections required NB: ◦ Top-scoring weight loss app = Noom Coach (70%) ◦ Top-scoring smoking cessation app = MyQuitBuddy (77%) ◦ Criterion score for acceptability not established

Mani et al., 2015[106]	Queensland, Australia	Mindfulness	Review and evaluation	None, only preparation via mindfulness training undertaken by raters prior to rating	No critique provided; authored by developers of the MARS

3.4.3 Inclusion of Condition-Specific Questionnaires

The studies assessing apps for smoking cessation and weight loss, and for heart failure, supplemented the MARS with condition-specific questionnaires. The authors' rationale for this additional stage indicated a need to incorporate assessment of clinical appropriateness of the app against published clinical management guidelines.[104] This concept is critiqued in detail below.

The study of heart failure apps by Masterson Creber et al.[105] supplemented the MARS with two instruments. Firstly, selected questions from an American standard for healthcare functionality, the Intercontinental Marketing Services (IMS) Institute for Healthcare Informatics Functionality Score,[107] were included, without modification to heart failure. Although these functionality questions are not specific to a chronic condition, they score apps on primary functions, such as recording information compared to guiding information or communicating information. The IMS Functionality Score[107] assesses whether apps collect, share, evaluate or "intervene" with health data. Future studies could (and arguably should) remove any questions from the MARS (or similar checklist) that become redundant following the integration of supplementary instruments. The ACDC included all IMS Functionality elements, and is compared with the IMS Functionality Score in Table 2.

Table 2: IMS Functionality Scoring Criteria compared to the ACDC

IMS Functionality Scoring Criteria	IMS Description	ACDC Equivalent
Inform	"Provides information in a variety of formats (text, photo, video)"	Q5.5. Visual Information: Is visual explanation of concepts – through charts, graphs, images, videos etc – clear, logical and correct?
Instruct	"Provides instructions to the user"	Q5.3. Quality and Accurate Information: Does the app accept and display correct, relevant information regarding the chronic condition?
Record: Collect data	"Able to enter and store health data on individual phone"	Q3.4. Intuitive Design: Is the app designed for intuitive use (e.g. identifiable data input fields, intuitive symbols and generous touch areas)?
Record: Share data	"Able to transmit health data"	Q3.5. Connection to Services: Does the app have capacity to send or connect data to another service (e.g. Apple Health)?
Record: Evaluate data	"Able to evaluate the entered health data by patient and provider, provider and administrator, or patient and caregiver"	Q5.1. Statistics: Does the app enable analysis of clinical data (e.g. produces statistics, graphs)?
Record: Intervene	"Able to send alerts based on the data collected or propose behavioural intervention or changes"	Q2.6. Positive Behaviour Change: Does the app encourage positive self-care practices (lifestyle or behavioural action), e.g. using reminders, tips or social influences?
Display	"Graphically display user entered data/output user entered data"	Refer to Q5.5. above AND Q5.3. Quality and Accurate Information: Does the app accept and display correct, relevant information regarding the chronic condition? (comprehensive controls over data entry; entered data consistent with displayed outputs)
Guide	"Provide guidance based on user entered information, and may further offer a diagnosis, or recommend a consultation with a physician/a course of treatment"	Q4.2. Automation: Does the app facilitate automation of tasks, e.g. with pre-populated fields, suggestions based on inputs, management of medical appointments, automated customer service?
Remind or Alert	"Provide reminders to the user"	Q4.6. Reminders: Does the app enable users to set reminders?

Communicate	"Provide communication with patients and/or provide links to social networks"	Q2.6. Positive Behaviour Change: Does the app encourage positive self-care practices (lifestyle or behavioural action), e.g. using reminders, tips or social influences? AND Q4.4. User Profile Setup: Does the app provide easy setup of a user profile, e.g. option to login via social media account?

The other incorporated measure, the HFSA's guideline for non-pharmacological management of heart failure,[108] was utilised to assess consistency with established guidelines. These additional metrics were not added to measure the severity and/or control of heart failure, rather to attempt to reference an appropriate authoritative clinical society specialising in that disease state. Whether this combination of checklists and questionnaires was successful was not reported by the authors, and require further application to gauge success.

3.4.4 Introduction of a Composite Score

The study of smoking cessation (n=60) and weight loss (n=60) apps published in New Zealand by Patel et al.[104] recognised the limitation of using a single rating scale such as the MARS. Patel's innovative approach, combining the MARS with another instrument, attempted to provide more holistic management of a particular condition. Their study utilised the MARS in combination with a condition-specific scale to produce a composite score: a smoking cessation score or a weight-loss criterion score (applied to the respective studies). A weighting of 45% was arbitrarily allocated to the condition-specific score, equivalent to the MARS component score (45%). A cultural relevance score, comprising 10% of the final score, was utilised for the local Indigenous Maori population to reflect whether the app attempted to reduce cultural barriers. This entailed questions specific to Maori culture, such as terminology, graphic images and cultural elements such as Whakapono (trust, honesty and integrity). The only other study to date reporting use of a composite clinical/app quality score has been the American heart failure study by Masterson Creber et al.[105] Together, these studies present an interesting illustration of how an instrument originally designed for rating mental health apps can be applied to other disease states.

Since each health condition would be expected to have unique clinical guidelines, it was impractical to add an additional score for this to the ACDC. A supplementary checklist for apps not created under the guidance of clinically-trained academics can contextualise the results to that specific health condition and produce a more realistic score.

The concept of a composite score, comprising of a checklist such as ACDC, supplemented by a condition score, is yet to be critiqued. However, accompanying a checklist with a selection of supplementary questionnaires has been recognised as the gold standard such as the cultural appropriateness criterion score in New Zealand or the HFSA guidelines for non-pharmacological management of heart failure.[108]

Reporting-wise, component scores assists when two apps present similar composite scores and only one app can be selected. Raters can subsequently select which individual component(s) is/are of greater prevalence and select one shortlisted app. Moreover, a composite score provides efficiency when identifying apps suitable for clinical use or trial.

3.4.5 Shortlisting Suitable Apps for Rating

The Masterson Creber heart failure management study[105] used a supplementary app store (Amazon App Store®), in addition to iTunes® (ACDC and MARS) and Android Google Play™ store (ACDC only) to shortlist apps for Android devices. The Amazon App Store® is unlikely to be relevant in the Australian market; it was launched in Australia with the Kindle® eBook reader, and is recognised as a 'third-party' app store for Android devices. The device setting requires changing to permit third-party stores to have apps downloaded to the device.[109] The Amazon App Store® offering includes a range of Kindle eBooks, but no health management apps comparable to the Android Google Play™ store or App Store®. Therefore, future applications of the ACDC to shortlist apps in the Australian market would be recommended to only utilise iTunes® and Android Google Play™ store.

However, the shortlisting process to identify the apps in the Patel study[104] presented a relatively crude shortlisting of apps compared to the screening conducted using the ACDC, and also retained apps created outside the home country (New Zealand) that may or may not be relevant to that country. Sixty apps per condition (smoking and weight loss) were shortlisted, and this number warranted numerous pairs of assessors, compared to a single team of three assessors utilising the ACDC to rate 10 asthma apps.

The third study, concerning mindfulness-based apps, was conducted by the authors of the MARS. Of 560 shortlisted apps, 25 met inclusion criteria. The process of shortlisting and rating was very similar to the original MARS study,[99] in that two raters were used to score apps, and no supplementary scale was incorporated. Grouping eligible apps based on mindfulness features such as "Lake Meditation", "Walking Meditation" or "Body Scanning" can simplify selecting the most dominant app feature.

3.4.6 Use of Consumers as Raters

Neither the MARS,[99] ACDC,[110] nor recently-published studies utilising the MARS,[104-106]utilised consumers as raters of apps in academic research. The developers of the MARS justified this by reference to their instrument for use by academic researchers. Similarly, the ACDC is designed for researchers and app developers. This represents a shortcoming in the body of research to date. Consumer involvement in earlier stages could provide greater insight into intricate user preferences and behavioural patterns during the course of the app's usage. Additionally, in participant groups, where the sub-population present cognitive or psychological impairments, it is advised to include this cohort earlier in the process.

The scoring criteria published to date have been developed for academic purposes: shortlisting and screening apps for quality, prior to consumer input. Hence, findings are limited at this stage in yielding an informed decision about the capacity for apps to facilitate self-care of one's chronic condition. Additionally, there is currently no concrete way for consumers to rank the quality of apps or to identify apps with evidence-based content.[111]

One exception to including consumers as raters in early stages is when the population with a target condition, such as smoking, includes a sub-population who present with cognitive or psychological impairment. Updated literature searches have revealed one recent mobile health study applying this concept.[111] More specifically, a study by Ferron utilised 21 smokers with "psychotic disorders" to rate the top nine out of 73 apps, as provided by two academic raters.[111] Initially, 100 apps were randomly selected from the eligible 535 apps and further shortlisting, such as 'unavailable for download' or 'not functional', reduced the number to 73. Two authors rated 73 apps with a four-point scale using a 20-item Adherence Index; however, three to five authors rated the usability domain. It would therefore seem the consumer-oriented 'blend' of consumer and academic raters can fill gaps otherwise missed by academics due to the complex nature of cognitive/psychological impairments within a target condition.

In terms of efficiency and accessibility of raters, consumers are optimally utilised when the sub-population presents a cognitive or psychological impairment. This particular combination warrants participants' participation during the app evaluation process. Consumer involvement to the rating process adds value by contextualising the participant group.

The Ferron study presents a new study design requiring further application to assess effectiveness.[111] Given the current progress in literature, the objectives now are to apply the ACDC to another chronic condition such as hypertension to build evidence for applicability across conditions. Current methods suggest supplementing the ACDC with a condition-specific scale acknowledged by an appropriate health body, such as The Heart Foundation or Diabetes Australia.

Moreover, the supplementary literature reviews did not reveal any alternative methods to rate or assess apps that have been published more recently than the MARS and ACDC.

3.4.7 Summary of Study Variations

Common features among studies in Table 1 include the use of a supplementary scale, except for one mindfulness study whose authors developed their own checklist.[106] The use of an app shortlisting process among these studies was utilised, but could be refined further down the shortlisting flowchart where variables such as duplicates, language, cost and recency of updates have been filtered. This would imply more stringent filtering among a cohort of more relevant shortlisted apps. For example, if only certain arts of meditation were sought, this could form a condition further down a flowchart to provide a more accurate list of shortlisted apps ready to rate.

Differences among studies in Table 1 include the shortlisting process used to gain the required output of apps to rate. One study did not specify weighting when using multiple checklists/scores, whereas the Patel et al. study,[104] allocated 10% for the cultural appropriateness criterion score and split the remaining scales evenly, as covered in Sections 3.4.2 and 3.4.4. Additionally, these studies do not challenge the ACDC's methods or findings for chronic disease apps, since the participant group does not exhibit cognitive or psychological impairments, as detailed in Section 3.4.6.

3.5 Other Recent Health App Developments

3.5.1 Apple HealthKit™ Apps

Thus far, health app usability studies utilising a checklist have included a clinical questionnaire, as outlined in Table 1. An environmental scan of latest health app developments located Apple's open source HealthKit™ framework as a highly feasible avenue to include in a clinical trial. Apps utilising Apple HealthKit™, such as those in Table 3, have been created by academic researchers in conjunction with mostly American major hospitals. This combination provides another layer of quality assurance through in-house university medical professionals, and a separate clinical questionnaire may not present a necessity compared to apps created by private non-tertiary organisations or individuals. At the time of development of the ACDC in 2016, all HealthKit™ apps such as AsthmaHealth® were not available using an Australian iTunes® account, except for "PPD ACT" due to its co-development by an Australian researcher. Thus far, no study has reported applying an instrument such as ACDC across HealthKit™ apps. It is important to note HealthKit™ apps with no publicly-stated university or research institute affiliation, such as OneDrop® (for diabetes), do exist, but are rare. Table 3 identifies HealthKit™ apps, their institutional affiliation(s) and accessibility using an Australian iTunes® account.

The subsequent HealthKit™ stage involves a consent process where the user learns more about the app's data collection intentions, points of contact, in-app measurements required and use of iPhone sensors such as camera or accelerometer. Furthermore, data processing, data privacy, right to withdraw from the study, potential need for follow-up questions and time commitment is clearly presented to the user and upon a quiz score of 100%, the consumer may continue using the app. Further, a verification email is sent to validate consumers.

Table 3: HealthKit™ App University Affiliations

App Name	Condition	App Icon	Validated and Developed by	Version Number	Version Date	Accessible in AU / USA?
Concussion Tracker*	Concussion		NYU Langone Medical Centre	1.1	17.01.2017	USA
C Tracker*	Hepatitis C		Boston Children's Hospital	1.1	15.02.2016	USA
Mole Mapper*	Melanoma		Oregon Health & Science University, Sage Bionetworks**	2.1.0	15.10.2015	USA
PPD ACT*	Post-partum Depression		University of North Carolina, National Institute of Mental Health	3.0.0	25.04.2017	Both due to AU co-researchers
SleepHealth*	Sleep Health		University of California San Diego, American Sleep Apnea Association	1.1	24.06.2016	USA
mPower	Parkinson's disease		University of Rochester, Sage Bionetworks**	1.4.1	18.03.2017	USA
MyHeart Counts	Heart Health / Cardiovascular Risk		Stanford University	2.0.1	09.02.2017	USA
Autism and Beyond	Autism		Duke University Medical Centre, University of Cape Town	1.0.3	03.03.2017	USA
EpiWatch	Epilepsy		Johns Hopkins University Epilepsy Centre	1.1	20.02.2016	USA

Not currently downloadable in the App Store® since data collection phase (Apple®) had finished:						
Asthma Health*	Asthma		Mount Sinai, Weill Cornell Medical College, LifeMap	N/A	N/A	Initially USA,
GlucoSuccess*	Diabetes		Massachusetts General Hospital	N/A	N/A	Initially USA
No publicly-disclosed university affiliation:						
StopCOPD*	COPD		DatStat; COPD Foundation	1.03	29.06.2016	USA
Notable HealthKit™ Apps in Development as of May 2017:						
TMC Care	Post-surgical care		Texas Medical Center	N/A	N/A	TBA
	Chronic conditions care app		Beth Israel Deaconess Medical Center	N/A	N/A	TBA
Notable CareKit Apps in Development as of May 2017						
OneDrop	Diabetes		(Private Interests) Informed Data Systems, Inc.	3.7	20.04.2017	Both

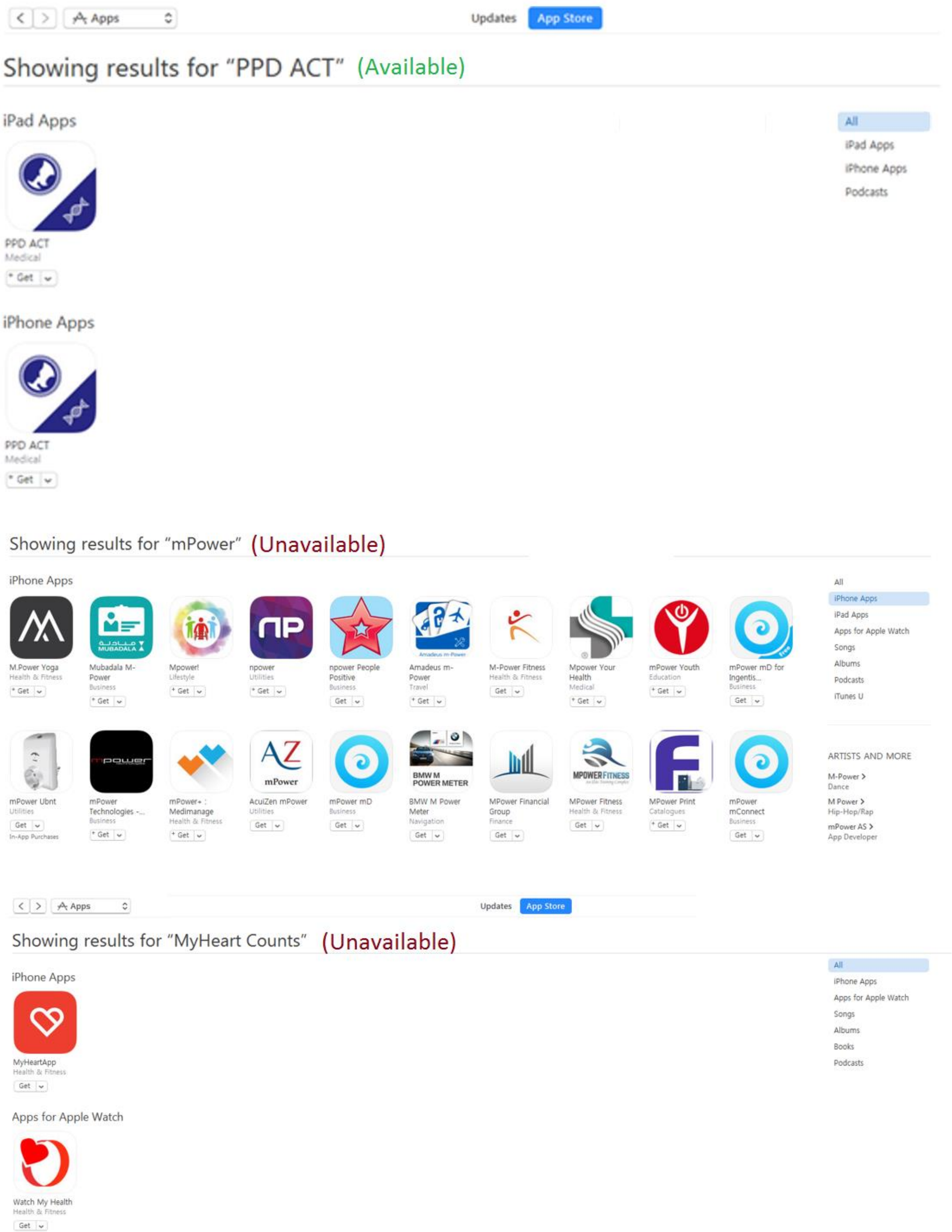
*Apps highlighted for participation on Apple's ResearchKit® homepage at the time of writing (May 2017). Remaining apps located via automated suggestions and manual App Store® searches.

**Sage Bionetworks is a not-for-profit research organisation.

Whilst assessing Apple HealthKit™ apps for potential rating, only one app with a university affiliation ("PPD ACT") was searchable with an Australian iTunes® account due to the Australian co-authors in Queensland. An American iTunes® account was required to download all other HealthKit™ apps for this study. Since this thesis provides an Australian perspective for Australian consumers using health apps to facilitate self-care of their chronic condition(s), the HealthKit™ and CareKit® apps were not examined further due to their vast unavailability on the Australian App Store®. Additionally, some HealthKit™ apps such as "Asthma Health" specifically required users to reside in the US, as per the End User License Agreement; however as advised through British technology webpage, "Asthma Health" is available in England, too, as of February 2016.[112]

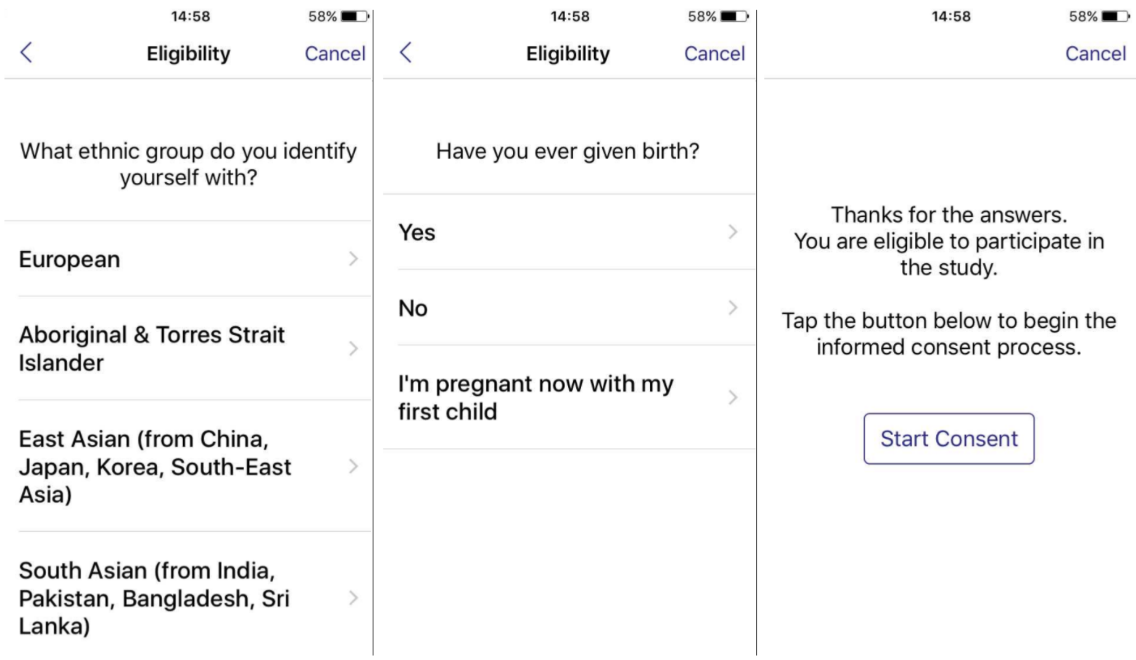
Accessibility was the driving issue concerning HealthKit™ apps, with only "PPD ACT" available on the Australian iTunes® store to this Australian-based researcher. As illustrated in Figure 1, an Australian iTunes® account could not locate the required HealthKit™ Apps. This would present a key accessibility issue for Australian consumers, and hence HealthKit™ apps were not used as the basis for trial of the ACDC. However, should more HealthKit™ apps become available in the Australian iTunes® store, this would be a highly suitable source of apps to assess for quality using the ACDC.

Figure 1: HealthKit™ app(s) (un)available on the Australian App Store



HealthKit™ apps commence with a series of eligibility questions, as outlined in Figure 2 . These questions vary depending on the chronic condition each app caters for but can include factors such as gender, smoking status, family medical history, former diagnosis of a condition such as COPD.

Figure 2: "PPD ACT" Eligibility Questions prior to Study Enrolment



3.5.2 Validating Shortlisting Protocol's Purpose

From the literature updates, this sub-section identifies whether there is any better way to identify a collection of relevant apps to be assessed using the ACDC.[110]

- **Health Fund Apps:** One line of enquiry was identifying a readily-available collection of Australian Health Insurance-endorsed apps such as HCF EyeCare (HCF), GymBetter (Medibank Private) and FoodSwitch (Bupa) outlined in Table 4; however, the features present in most apps made them unsuitable for clinical use, and thus, rating.

Table 4: Australian Health Funds and their Apps

Insurer	App Name	App Icon	Version	iOS/Android	Purpose
HCF	Quit Smoking		1.1	Both	Lifestyle Management
	Be Happier		1.0	Both	Lifestyle Management
	HCF EyeCare (by Jon Harsem)		2.0.1	iOS	Informational
	Get Fitter		1.1	Both	Lifestyle Management
	HCF Eat Better		1.1	Android	Informational
	HCF My Membership		2.8.0	Both	Membership Management
Medibank Private	Daisy		1.1.1	Both	Informational
	GymBetter		1.3.1	Both	Informational
	Medibank Symptom Checker		1.0.2	iOS	Informational
	Medibank Energy Balancer		1.0	Both	Entertainment
	Medibank Mobile		2.0.1	Both	Membership Management
Bupa	FoodSwitch		1.93	Both	Informational
	Bupa Boost (UK)		2.4.1	Both	Lifestyle Management
	Living With and Beyond Cancer		1.0	iOS	Claim Management
	Bupa Australia		1.11.1	Both	Membership Management
	Bupa Connect		1.0.0	Both	Claim Management
nib	nib Health Insurance		4.3.0	Both	Claim Management
HBF	HBF Health		2.0.2	Both	Membership Management

	HBF Pocket Health		1.7.7	Both	Health Record (data entry, no management)
HIF	HIF Smart Claim		2.0.10	Both	Claim Management

- **HealthKit™ Apps:** Another approach was to consider rating HealthKit™ apps designed by a university with input from health professionals (e.g. "SleepHealth" and "MyHeart Counts"), as outlined in Section 3.5.1. However, only one HealthKit™ app was available to Australian iTunes® accounts; therefore, the decision was made to disregard HealthKit as an alternative source of apps that could be subjected to assessment using the ACDC. It is important to note HealthKit™ apps with a university affiliation include a data collection component for researchers to perform studies.[113]

- **Google Play™ store and iTunes® Apps:** Appraising and subsequently evaluating a chronic condition using publically-available Google Play™ store and iTunes® apps was the chosen line of enquiry due to accessibility and its ubiquitous nature. These platforms are the two most common software platforms for consumers[114] and contain by far the most abundant range of health apps compared to other mobile platforms.

Using consumers as raters: The intention of the protocol [110] was academic screening of apps, hence use of consumers are not justified in this stage. However, the subsequent stage of the protocol, namely, the evaluation of a single app in a consumer's day-to-day management of their health condition, has scope to include consumers in certain circumstances. For example, including consumers as raters when they exhibit cognitive or psychological impairments[111] to be included as raters alongside academics, as outlined in Section 3.4.6,. and the latter publication is the line of choice

Since the Australian health fund and Apple® HealthKit™ lines of enquiry were not feasible, it was decided to proceed with trialling the shortlisting protocol.

In conclusion, this chapter facilitated the decision to trial the shortlisting protocol,[110] and if the protocol subsequently identified a manageable suite of apps, the other components of the ACDC (evaluation of the shortlisted apps) would be applied.

4 CHAPTER 4 Results: Critical appraisal of Asthma Management Apps (Sub-Study 1)

4.1 Preface

This chapter presents the results from application of the ACDC protocol that was presented in the previous chapter. Research Objective 3a, “Critical appraisal of health apps for that chronic condition (asthma),” is addressed in this chapter. The following chapter describes a validation study using apps for self-monitoring of hypertension, where all asthma apps were rated between 11 July 2016 and 04 August 2016.

Chronic diseases, stipulated by the World Health Organisation (WHO) as being responsible for 60% of worldwide deaths, were shortlisted for both ACDC sub-studies. According to the WHO, these conditions include “heart disease, stroke, cancer, chronic respiratory diseases and diabetes.”[115]

The word ‘asthma’ was used to search for asthma apps in the Apple and Android online stores. Other researchers have shortlisted apps using search terms as well, and then excluded apps outside the inclusion criteria,[97,99] rather than searching within broader categories listed in app stores. The apps needed to be asthma-focussed and have self-management capability. If the apps included “irrelevant content…or are faulty”[99] (determined by user feedback and ratings), they were excluded. There was no exclusion based on the country of origin, provided the app was available in English; however, the apps were evaluated for relevance to Australian asthma management guidelines. There need not have been an equal number of Apple and Android apps evaluated. It was estimated 20 apps in total would meet the inclusion criteria for evaluation, comprising exclusion of duplicates, non-English apps, paid and apps not updated within 12 months from date of shortlisting. The remaining apps were initially separated by core function such as clinical asthma management, eBook, exercise or novelty/entertainment-related, in addition to asthma not exhibiting the core function of the app. At the time of shortlisting asthma smartphone (not tablet computer) apps in 2016, there were 530 “popular” health and fitness iPhone apps[116] (as opposed to iPad apps) in Apple’s App Store® (207 appeared in response to ‘asthma’ as the search term) and 495 smartphone apps (104 for asthma) in the Android Google Play™ store.[117] However, some incorrectly-classified apps, such as “Betta Life International”, appeared in the asthma search results. Additionally, some apps were only available in foreign languages (Chinese and German). Other apps sounded useful by their title, for example, “Breathing Gym”, but lacked asthma-related content. A preliminary search for “asthma” apps identified some required payment, for example, “7 Keys to Manage Child Asthma” at AU$3.55.

4.2 Introduction: Validation of the ACDC using Asthma Management Apps

According to the Australian Bureau of Statistics, 10.2% of Australians have asthma.[118] Worldwide, asthma affects 235 million people.[119] Although similar proportions of males and females are reported with the condition, there is a difference in prevalence between age groups. For example, Australian data indicate 11.4% of males aged 0-14 years have asthma, compared to 7.2% of females; however, asthma is more prevalent in females over 15 years old than males.[118]

Asthma is an inflammatory condition that involves constriction of the airways with increased mucus production, making breathing increasingly difficult.[120] Considering the range of symptoms, people with asthma would benefit from self-monitoring subjective symptoms, such as shortness of breath, and objective data, such as peak respiratory flow.

4.2.1 Challenges of Asthma

Asthma was chosen as the first condition to test the ACDC because it is a chronic condition from which objective data, such as peak flow readings, can be generated and monitored. Furthermore, the National Asthma Council was seeking to update their “Asthma Buddy” app, which, as of 2017, was unavailable in the App Store® and Android Google Play™ store. Therefore, a second reason for the initial focus on asthma was to potentially assist the Council in updating their asthma app.[121]

Challenge 1: Symptoms. Asthma is commonly a symptomatic condition (people experience shortness of breath, wheeze, cough) affecting quality of life.[122] The qualitative study within this thesis postulated exacerbation of symptoms might motivate people with asthma to take action (use medication, monitor symptoms, seek medical advice, modify activity);[65] however, those with chronically undermanaged asthma might be permanently symptomatic, and not realise they could achieve a 'better normal', so expecting a health consumer to recognise symptoms is unreliable.[122,123]

Challenge 2: Monitoring. Monitoring asthma with the spirometry gold standard is ideal, but is limited to a clinical setting.[124] Peak expiratory (or respiratory) flow has some use in the community, but is limited by variability in measurements and relies on technique due to the mechanical nature of the peak flow meter.[125] Due to limitations of PEF, it is recommended PEF measurements be interpreted in conjunction with subjective data such as the cough Visual Analogue Scale.[126] However, despite its limitations, PEF remains the mode of quantitative self-monitoring.[127]

Challenge 3: Adherence. Non-adherence with asthma action plans has been noted as a great concern when managing one's condition, particularly when reducing hospitalisations and ongoing treatment.[128] Improving adherence involves a multi-faceted approach, namely enhancing technology/health literacy,[110] as previously discussed in this thesis, but also other considerations such as catering for the digital age via apps and "empowering" the patient.[128] Nevertheless, adherence presents a resolvable challenge to self-monitoring.

Moreover, given the aforementioned challenges of asthma, namely its symptomatic nature, monitoring and adherence, the condition lends itself to self-monitoring. This will complement the qualitative and quantitative data captured via an app, assist with quality of life and help adherence consistency.[65,125] This suitability of asthma (and need) for self-monitoring has been recognised by technology developers in the emergence of apps for asthma self-monitoring available in app stores.

4.2.2 Prevalence and Risks of Uncontrolled Asthma

Asthma would also benefit from the use of self-management apps due to the established correlation between medication non-adherence and asthma control.[129] For example, published studies in asthma management have highlighted attitudinal influences towards medication adherence and lifestyle changes affecting asthma control. Significant improvement ($p<0.05$) in adherence has been reported from focussed asthma management, demonstrated in the following adherence measures: "I am not sure inhaler type medicines work well," "Taking medicines more than once a day is inconvenient" and "Sometimes I skip my inhaler to use it over a longer period".[129]

Additionally, the uptake of mobile apps specific to chronic conditions such as asthma has been understudied. The National Asthma Council of Australia's "Asthma Buddy"[130] app and the National Prescribing Service (NPS) of Australia's "MedicineList+"[131] app are designed for Australian consumers using Australian standards. "MedicineList+" integrates Australian-specific medication lists, and consumers can download prescription information directly from their Australian pharmacy. There is no published research on either app.

Biofeedback for chronic conditions enables another dimension of monitoring using peripheral devices.[132] There are limited examples of biofeedback used successfully in Australia; for example, "AirSonea"™ by Respiri® (formerly, "iSonea"® prior to 07.12.2015[133]) captures biofeedback data[134] from a wheeze/cough, transmitted wirelessly to the consumer's smartphone. "AirSonea"™ reports uptake greater than expected;[135] however, there are no independent scholarly critiques of this device. Biofeedback involves measurement of bodily processes such as brain wave activity but also can be used to monitor conditions such as asthma and hypertension.[136] Outside Australia, there are also biofeedback devices for sleep apnoea[15] that take advantage of built-in sensors and computing power of 'smartphones'. This thesis advocates for more evidence to prove consistent efficacy.

4.2.3 Studies in which Asthma Self-Monitoring has been Evaluated

The purpose of this sub-section is to critique asthma app studies.

A Cochrane review[137] of two randomised-controlled trials (RCTs) of tablet and smartphone apps for asthma management indicated a paucity of research in self-management practices and conflicting evidence regarding the effectiveness of apps for asthma management. Furthermore, statistically significant changes in adherence when using asthma apps were not consistently found in the two RCTs. One British RCT in the review involved comparing paper-based monitoring to custom-built app monitoring (n=288); participants aged 12 years and above presenting poorly controlled asthma (>1.5 Asthma Control Questionnaire) were included. This RCT required two daily peak flow readings of a purpose-built web application called “t+” in exchange for immediate feedback via a ‘traffic light’ system. Participants who reached the amber zone twice or the red zone once, in accordance with national asthma guidelines, within the study were telephoned by an asthma nurse, illustrating the interface between self-monitoring and clinical care. The same RCT reported increased quality of life (QoL) scores at the six-month follow-up. However, the study was not able to conclusively suggest the increase in QoL was entirely due to self-monitoring.

The other RCT, a six-month Taiwanese study by Liu and colleagues (n=120), compared paper-based asthma diary /action plan to a custom university-built app, requiring participants to record PEF and asthma symptoms. This study identified an “incremental improvement of peak expiratory flow rate” between months four and six. The two RCTs had limitations with “blinding of participants and personnel” with regard to “participants’ performance and the observed effect.”[137] The studies reviewed were from Taiwan[138] and the United Kingdom (UK)[71]; there were no Australian or New Zealand studies. Despite the equivocal findings, the authors supported the use of technological innovation to increase poor adherence to asthma management. Notwithstanding the difference in the prevalence of asthma in Australia, different healthcare practices and management guidelines, it is plausible similar results could be achieved when replicating the study in Australia, the focus country of this thesis.

4.3 Aims

The aims of this chapter align with aim 2b from the overall aims, namely: [to] “evaluate available health apps for a particular health condition, via critical appraisal of health apps for that condition.” ‘Critical appraisal’ has been conducted by following the ACDC peer-reviewed protocol[110] for the current condition of interest.

4.4 Methods

The methods follow those of the published protocol[110]. Exceptions, specific adaptations and additional steps necessitated in this trial are detailed in the following sections.

4.4.1 Phase 1: Selection of Apps

As per the published protocol,[110] the custom-designed PRISMA-inspired flow diagram was used to filter asthma apps available via the App Store® and Android Google Play™ store using the word 'asthma'. Where duplicates presented among shortlisted apps, the iOS version was selected, since iOS applies more stringent app selection guidelines compared to Android.[139-141]

4.4.2 Phases 2 and 3: Evaluation of Apps

A customised dummy patient profile was required. The profile was designed to represent characteristics and risk factors typical of a person with asthma. The resulting asthma profile is presented in the published protocol. Additional resources such as Instructions for Raters (Appendix 7: ACDC Instructions for Raters (*JMIR* Appendix)) remained as per the protocol.

An iPad® running software version 10.x.x and a Samsung smartphone was used for rating shortlisted apps. The same three raters undertook "simulated use of the apps" as per the published protocol.[110] Again, two apps per platform were rated by consensus (n=4).

The ACDC was used to rate shortlisted apps as per the published protocol.[110] Qualtrics® was used to capture checklist responses, and SPSS® v24 was utilised for data analysis.

All ACDC variables were represented with a scoring option of 0, 0.5 or 1.0 within constructs labelled "Engagement, Functionality, Ease of Use, and Information Management," as per the ACDC protocol.[110] In Tables 2-5, all ACDC variables are represented with a consensus value of 0, 0.5 or 1.0, as per the ACDC protocol.[110] Subtotals for each construct, and a total score for each app, are presented. For the apps rated by consensus, a 'projected' total (the total multiplied by three) is presented to enable direct comparison with apps scored by three raters independently, where the sum from each rater was totalled.

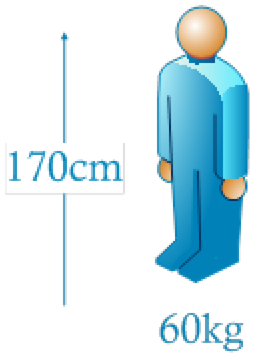
Again, two-way mixed ICC was calculated for each of the four constructs of the ACDC. Where the ICC was less than 0.7,[142] a moderated score (achieved by consensus) was determined; in all cases, the moderation achieved a recalculated ICC of at least 0.7.

4.4.3 Context-Specific Considerations for the Asthma Sub-Study

To facilitate individual rating, the first two apps from the iOS and Android platforms (based on the randomised list) were rated by consensus. This number was deemed suitable to agree on nuances and provide confidence to each individual rater. This has been established in the published protocol.[110]

Figure 3 illustrates the test dummy profile before and after familiarisation of the rating panel with shortlisted apps. The dummy profile describes a 30-year-old female with uncontrolled asthma, as this study does not focus on minors. “Reliever medication” is a condition-specific variable for asthma which was included in the dummy profile. Other asthma-specific variables included primary/backup medication plus dosage and frequency, any assumptions and triggers. Other profile variables, such as exercise frequency and hospitalisation records, were determined based on the targeted participant demographics, and required data input fields from shortlisted asthma apps. The profile was then locked down for individual rating, and no additional features were found to be required during individual rating.

Ms Test Dummy
01.01.1987 (F)
(version before updates)



Profile before Updates

- Uncontrolled asthma since [appropriate age]
- Enters daily peak flow readings into app
- Understands a reading [above/below] 630 L/min requires adjustment of therapy

- Athletic
- Asthma since childhood
- Variable control over the years
- Compliance and adherence to medication generally good

Triggers:

- Chest cold, pollen/ fungal spores, sudden weather changes, cold/dry air

Reliever:

- Ventolin® (salbutamol)
  2 puffs as needed

Preventer:

- Seretide® (fluticasone)
  2 puffs / 12 hours

Assumptions:

- Acceptable reading technique
- Takes no other medication apart from [OTC tablets]
- Exacerbations during inconsistent self-management period: chest cough, wheezing, chest tightness

Profile after Updates

- Uncontrolled asthma since [appropriate age]
- Enters daily peak flow readings into app
- Understands a reading [above/below] 630 L/min requires adjustment of therapy

- Athletic
- Running three times per week
- Asthma since childhood
- Variable control over the years
- Hospitalised once after chest infection
- Compliance and adherence to medication generally good

Triggers:

- Chest cold, pollen/ fungal spores, sudden weather changes, cold/dry air, smoke, harsh chemicals, strong smells/sprays

Reliever:

- Ventolin® (salbutamol)
  2 puffs as needed
  14.07.2014 – 14.07.2050

Preventer:

- Seretide® (fluticasone 125mcg/ salmeterol 25mcg)
  2 puffs / 12 hours
  14.07.2010 – 14.07.2050

Assumptions:

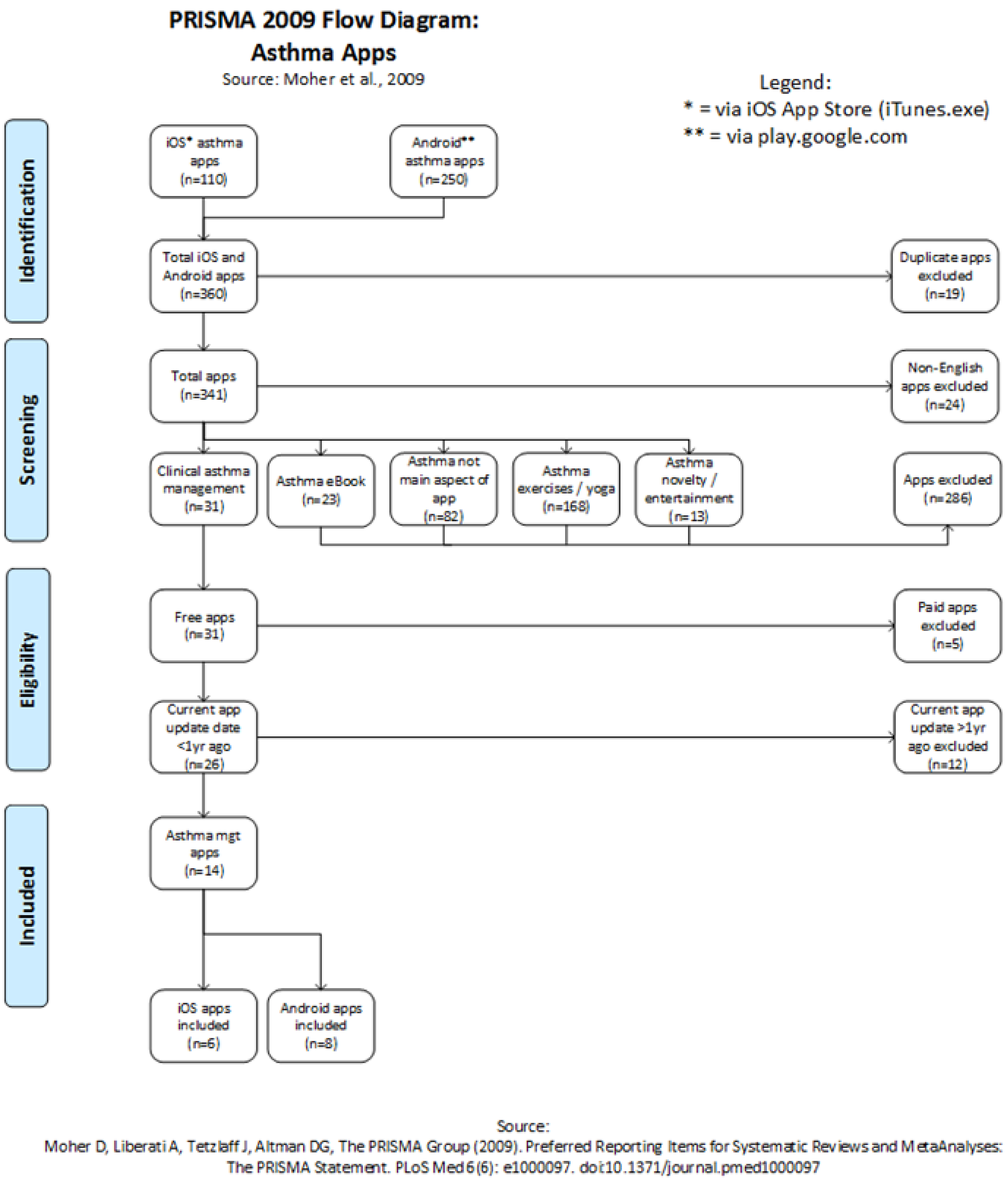
- Acceptable reading technique
- Takes no other medication apart from [OTC tablets] when required
- To test reporting functions:
  GP: Dr Test Account (use 2nd rater's email)
  NoK: Mummy Dummy (use 3rd rater's email)
- Postcode/ ZIP: [20001]
- City: [Washington DC]
- Exacerbations during inconsistent self-management period: chest cough, wheezing, chest tightness

Figure 3: Before and After Asthma Test Dummy Profiles

4.5 Results

4.5.1 Shortlisted Asthma Management Apps

In total, 365 apps for self-management of asthma (115 Apple and 250 Android) were subjected to the custom-designed shortlisting process. Of these, 19 asthma apps were duplicated between the two platforms, and the iOS version of each duplicate was retained (Figure 4).



[1] Anderson K, Burford O, Emmerton L. App Chronic Disease Checklist: a method to evaluate mobile apps for chronic disease self-management. JMIR Res Protoc. 2016 [doi:10.2196/resprot.6194]. [Medline: 27815233]

Figure 4: Asthma App Shortlisting Process using the Published PRISMA-Inspired Flow Diagram[1]

Table 5 presents a summary of all 14 apps e.g. country of origin, last update prior to rating, version and key functions. Four apps originated from America, with two from Germany and one from eight other countries. In Tables 6-9, all ACDC variables are represented with a consensus value of 0, 0.5 or 1.0, as per the ACDC protocol.[110]

Tables 10-15 use the same table and rating structure but list the individual ratings from three raters and the ICC for each construct to illustrate the degree of consensus between raters.

Table 5: Shortlisted Asthma Clinical Management Apps

	App Icon	Country of Origin	Last Update Prior to Rating	Version	Key Functions other than Data Entry/Health Tracking	Reason for Exclusion*
Android						
“Asthma Tick”		India	14 Jul 2015	1.2.0	None	N/A
“AsthmaMD”		America	24 Jan 2016	1.7	Graphical representation Connection to peripheral User Profile Sharing of results with GP Reminders	N/A
“Peak Flow Manager”		Latvia	04 Jan 2016	1.51	Graphical representation Sharing with social media	N/A
“Peakflow”		England	09 Apr 2015	1.2	Limited graphical representation Export to cloud/ SD card	N/A
“Scripps Health Asthma Coach”		America	03 May 2015	3.1.2	N/A	Required access code, as described in Section 6.4.2, namely “Please enter your 1-time access code to be guided through 3 quick set up screens”
“AsthmaPlot”		Russia	04 Apr 2015	1.0	Limited graphical representation	N/A

“MyPeakFlow”		France	04 Feb 2016	1.0.005	None	N/A
“AMS Asthma”		Germany	10 Nov 2015	1.1	Connection to peripheral	N/A
iOS						
“Asthma Coach”		Ireland	12 Aug 2015	1.0.1	Sharing of results with GP Reminders	N/A
“Asthma Patient Companion” aka (“My Asthma Manager”)		America	27 Mar 2015	2.26.8	Graphical representation Reminders	N/A
“Asthma Tracker”		Germany	06 Feb 2016	2.0.1	Apple Health/Smartwatch compatible Reminders	N/A
“AsthmaPortal”*		Singapore	04 Dec 2015	2.1	N/A	Singapore clinic code required as first prompt before app usage
“Asthma NZ”* (“Smart Inhaler”)		New Zealand	15 Feb 2016	5.1	N/A	Downloadable but not accessible by Australian consumers
“AAP Asthma Tracker for Adolescents”*		America	07 Mar 2015	1.25.13	N/A	“Clinician visits” code required

NB: Asterisked apps denote exclusion from rating

*All apps were rated between 11 July 2016 and 04 August 2016

4.5.2 Results for Asthma Apps via Consensus (between Three Raters)

The first app rated by consensus, “Asthma Coach” (iOS), demonstrated a total score 28.5/72.0 (Table 6). The highest-scoring construct of this app was Functionality, with a consensus score of 3.0/6.0. Addition of entries whilst in offline mode and customisable reminders would have been welcomed. “Asthma Coach” from the Asthma Society of Ireland is no longer available in the App Store® as of January 2018; however, a physical air quality sensor featuring a downloadable app is listed on the website.[143]

“Asthma Patient Companion” (iOS), demonstrated the highest total score of those rated by consensus (Table 7). The highest-scoring construct of this app was Information Management, with a consensus score of 5.5/6.0. The peak flow input area was difficult to locate by the raters; however, the credible use of an American institution’s logo provided comfort to the raters, in addition to a clean and simple user interface.

The highest-scoring constructs for “Peak Flow Manager” (Android) were Functionality and Ease of Use, each with a consensus score of 3.5/6.0 (Table 8). Although the addition of peak flow entries and associated notes were permitted in offline mode, no reminders could be successfully set by the raters.

The final app rated via consensus, “Asthma Plot” (Android), demonstrated the lowest total score of all assessed apps (Table 9). The highest-scoring constructs of this app were Functionality and Ease of Use, each with a consensus score of 2.0/6.0. The lowest score of 1.0/6.0 out of all apps rated via consensus was for Information Management. More in-depth statistics and reminders would have been welcomed; however, one feature was that data could be added in offline mode.

No moderation was required for any variable within the Ease of Use construct. Ten responses out of 54 (three raters x six variables x three constructs) were moderated down, and 14 responses out of 54 were moderated upwards by 0.5.

Table 6: Consensus Score for "Asthma Coach" V1.0.1, by Asthma Society of Ireland (iOS, rated August 2016)

Construct	Variable	ACDC Survey Questions	Consensus Score
Engagement	Gamification	Contains gaming principles (such as digital rewards, prizes, leaderboards, badges, aggregated readings or competitions)	0.0
	Customisation	Permits customisation of features (e.g. sound, content, notifications	0.5
	Interactivity	Allows free-text reflections alongside clinical data	0.0
	Engagement through use of plug-ins	Connects with a peripheral device	0.0
	Self-awareness	Encourages user to develop self-reflection and/or increased self-awareness	0.5
	Positive behaviour change	Encourages positive self-care practices e.g. using reminders, tips or social influences?	0.5
	Subtotal		**1.5/6.0**
Functionality	Health warnings	Produces warnings about, or highlights, out-of-range readings	0.5
	Feedback	Provides tactile, visual and/or sound feedback	0.5
	Structural navigation	Facilitates sequential/appropriate navigation	1.0
	Intuitive design	Presents intuitive use e.g. identifiable data input fields, intuitive symbols, generous touch areas	0.5
	Connection to health services	Sends or connects data to another service	0.0
	Performance power	Responds to app features (functions) and components (buttons/menus	0.5
	Subtotal		**3.0/6.0**
Ease of Use	Holistic usability	Captures self-management tasks easily in a single app	0.5
	Automation	Facilitates automation of tasks e.g. pre-populated fields, suggestions based on inputs, management of medical appointments, automated customer service	0.0
	Medical and technical jargon	Omits confusing (medical and/or technology) jargon	1.0
	User profile setup	Provides easy setup of user profile, e.g. option to login via social media account	0.5
	Offline mode	Operates core functionality in offline mode	0.0
	Reminders	Enables users to set reminders	0.5

	Subtotal		**2.5/6.0**
Information Management	Statistics	Permits analysis of clinical data e.g. produces statistics, graphs	0.0
	Privacy and data security	Allows secure data input and export e.g. password management, encryption, privacy statement, cloud backup	0.5
	Quality and accurate information	Accepts and displays correct, relevant information	0.0
	Quantity of information	Offers concise but still comprehensive information	1.0
	Visual information	Illustrates clear and logical charts, graphs, images, videos etc	0.5
	Credibility	Presents credible logo and cites research	0.5
	Subtotal		**2.5/6.0**
Total			**9.5/24.0**
Projected Total*			**28.5/72.0**

*Totals for apps rated by consensus measurement have been multiplied by three to produce the same denominator as individually-rated apps

Table 7: Consensus Score for “Asthma Patient Companion” V2.26.8, by @Point of Care (iOS, rated August 2016)

Construct	**Variable**	**ACDC Survey Questions**	**Consensus Score**
Engagement	Gamification	Contains gaming principles (such as digital rewards, prizes, leaderboards, badges, aggregated readings or competitions)	0.0
	Customisation	Permits customisation of features (e.g. sound, content, notifications	0.0
	Interactivity	Allows free-text reflections alongside clinical data	0.0
	Engagement through use of plug-ins	Connects with a peripheral device	0.0
	Self-awareness	Encourages user to develop self-reflection and/or increased self-awareness	1.0
	Positive behaviour change	Encourages positive self-care practices e.g. using reminders, tips or social influences?	0.5
	Subtotal		**1.5/6.0**
Functionality	Health warnings	Produces warnings about, or highlights, out-of-range readings	0.0
	Feedback	Provides tactile, visual and/or sound feedback	0.0
	Structural navigation	Facilitates sequential/appropriate navigation	1.0
	Intuitive design	Presents intuitive use e.g. identifiable data input fields, intuitive symbols, generous touch areas	1.0
	Connection to health services	Sends or connects data to another service	0.5
	Performance power	Responds to app features (functions) and components (buttons/menus	0.5
	Subtotal		**3.0/6.0**
Ease of Use	Holistic usability	Captures self-management tasks easily in a single app	0.5
	Automation	Facilitates automation of tasks e.g. pre-populated fields, suggestions based on inputs, management of medical appointments, automated customer service	0.0
	Medical and technical jargon	Omits confusing (medical and/or technology) jargon	0.0
	User profile setup	Provides easy setup of user profile, e.g. option to login via social media account	0.5
	Offline mode	Operates core functionality in offline mode	0.0
	Reminders	Enables users to set reminders	0.5

	Subtotal		**1.5/6.0**
Information Management	Statistics	Permits analysis of clinical data e.g. produces statistics, graphs	1.0
	Privacy and data security	Allows secure data input and export e.g. password management, encryption, privacy statement, cloud backup	0.5
	Quality and accurate information	Accepts and displays correct, relevant information	1.0
	Quantity of information	Offers concise but still comprehensive information	1.0
	Visual information	Illustrates clear and logical charts, graphs, images, videos etc	1.0
	Credibility	Presents credible logo and cites research	1.0
	Subtotal		**5.5/6.0**
Total			**11.5/24.0**
Projected Total*			**34.5/72.0**

*Totals for apps rated by consensus measurement have been multiplied by three to produce the same denominator as individually-rated apps

Table 8: Consensus Score for “Peak Flow Manager” V1.51, by Eduard Volkov (Android, rated August 2016)

Construct	Variable	ACDC Survey Questions	Consensus Score
Engagement	Gamification	Contains gaming principles (such as digital rewards, prizes, leaderboards, badges, aggregated readings or competitions)	0.0
	Customisation	Permits customisation of features (e.g. sound, content, notifications	0.5
	Interactivity	Allows free-text reflections alongside clinical data	1.0
	Engagement through use of plug-ins	Connects with a peripheral device	0.0
	Self-awareness	Encourages user to develop self-reflection and/or increased self-awareness	0.0
	Positive behaviour change	Encourages positive self-care practices e.g. using reminders, tips or social influences?	0.0
	Subtotal		**1.5/6.0**
Functionality	Health warnings	Produces warnings about, or highlights, out-of-range readings	0.5
	Feedback	Provides tactile, visual and/or sound feedback	0.5
	Structural navigation	Facilitates sequential/appropriate navigation	0.0
	Intuitive design	Presents intuitive use e.g. identifiable data input fields, intuitive symbols, generous touch areas	1.0
	Connection to health services	Sends or connects data to another service	0.5
	Performance power	Responds to app features (functions) and components (buttons/menus	1.0
	Subtotal		**3.5/6.0**
Ease of Use	Holistic usability	Captures self-management tasks easily in a single app	0.0
	Automation	Facilitates automation of tasks e.g. pre-populated fields, suggestions based on inputs, management of medical appointments, automated customer service	0.5
	Medical and technical jargon	Omits confusing (medical and/or technology) jargon	1.0
	User profile setup	Provides easy setup of user profile, e.g. option to login via social media account	1.0
	Offline mode	Operates core functionality in offline mode	1.0
	Reminders	Enables users to set reminders	0.0

	Subtotal		**3.5/6.0**
Information Management	Statistics	Permits analysis of clinical data e.g. produces statistics, graphs	0.5
	Privacy and data security	Allows secure data input and export e.g. password management, encryption, privacy statement, cloud backup	0.5
	Quality and accurate information	Accepts and displays correct, relevant information	0.0
	Quantity of information	Offers concise but still comprehensive information	0.0
	Visual information	Illustrates clear and logical charts, graphs, images, videos etc	0.5
	Credibility	Presents credible logo and cites research	0.0
	Subtotal		**1.5/6.0**
Total			**10.0/24.0**
Projected Total*			**30.0/72.0**

*Totals for apps rated by consensus measurement have been multiplied by three to produce the same denominator as individually-rated apps.

Table 9: Consensus Score for "Asthma Plot" v1.0, by Programstroy (Android, rated August 2016)

Construct	Variable	ACDC Survey Questions	Consensus Score
Engagement	Gamification	Contains gaming principles (such as digital rewards, prizes, leaderboards, badges, aggregated readings or competitions)	0.0
	Customisation	Permits customisation of features (e.g. sound, content, notifications	0.5
	Interactivity	Allows free-text reflections alongside clinical data	0.5
	Engagement through use of plug-ins	Connects with a peripheral device	0.0
	Self-awareness	Encourages user to develop self-reflection and/or increased self-awareness	0.5
	Positive behaviour change	Encourages positive self-care practices e.g. using reminders, tips or social influences?	0.0
	Subtotal		**1.5/6.0**
Functionality	Health warnings	Produces warnings about, or highlights, out-of-range readings	0.5
	Feedback	Provides tactile, visual and/or sound feedback	0.0
	Structural navigation	Facilitates sequential/appropriate navigation	0.0
	Intuitive design	Presents intuitive use e.g. identifiable data input fields, intuitive symbols, generous touch areas	0.5
	Connection to health services	Sends or connects data to another service	0.0
	Performance power	Responds to app features (functions) and components (buttons/menus	1.0
	Subtotal		**2.0/6.0**
Ease of Use	Holistic usability	Captures self-management tasks easily in a single app	0.0
	Automation	Facilitates automation of tasks e.g. pre-populated fields, suggestions based on inputs, management of medical appointments, automated customer service	0.0
	Medical and technical jargon	Omits confusing (medical and/or technology) jargon	1.0
	User profile setup	Provides easy setup of user profile, e.g. option to login via social media account	0.0
	Offline mode	Operates core functionality in offline mode	1.0
	Reminders	Enables users to set reminders	0.0

	Subtotal		**2.0/6.0**
Information Management	Statistics	Permits analysis of clinical data e.g. produces statistics, graphs	0.5
	Privacy and data security	Allows secure data input and export e.g. password management, encryption, privacy statement, cloud backup	0.0
	Quality and accurate information	Accepts and displays correct, relevant information	0.0
	Quantity of information	Offers concise but still comprehensive information	0.0
	Visual information	Illustrates clear and logical charts, graphs, images, videos etc	0.5
	Credibility	Presents credible logo and cites research	0.0
	Subtotal		**1.0/6.0**
Total			**6.5/24.0**
Projected Total*			**19.5/72.0**

*Totals for apps rated by consensus measurement have been multiplied by three to produce the same denominator as individually-rated apps

4.5.3 Results for Asthma Apps rated Independently

“Asthma Tracker” required minimal reconvening after individual rating, with two Engagement sub-constructs requiring adjustment (Table 10). The user interface was easy to use, with colour-coding indicating out of range readings present. The highest-scoring construct of this app was Ease of Use, at 8.0/18.0.

“Asthma Tick”, the first app to be rated independently by three raters, held the most consistent Engagement construct ICC (Table 11). The highest-scoring construct of this app was Functionality and Ease of Use, both at 6.0/18.0. Additionally, three of the four domains did not require moderation of the three raters’ scores, as their ICC values were >0.7. In the construct requiring moderation, two variables required negotiation between the three raters for the respective scores to attain an acceptable ICC. “Asthma Tick” presented rather elementary user interface design and data presentation lacked structure and clarity.

“AMS Asthma” (Table 12) presented its highest-scoring construct with Functionality at 8.0/18.0 featured adequate offline mode access compared to all rated apps, with all core input features available without internet access. However, no privacy or security features were present.

“AsthmaMD” exhibited the highest overall score out of all assessed apps (Table 13). The highest-scoring construct of this app was Information Management, with a consensus score of 13.5/18.0. Scores in the Functionality domain/construct required considerable negotiation to attain an acceptable ICC. “AsthmaMD” was funded by a university grant in California and has featured on American breakfast television, demonstrating commitment to reaching potential users.[144]

“Peak Flow” presented the most significant difference in opinion for the Customisation sub-construct (Table 14) out of all apps rated. The highest scoring construct of this app was Functionality, with a score of 9.0/18.0. “Peak Flow” presented a user-friendly interface, similar to “Asthma Tracker”. Clinical data could be inputted during offline mode but no working reminders or credible logos were available.

The final asthma app scored, “myPeakFlow”, exhibited a lower adjusted total score than the original score, and the lowest total score of any app overall: 10.5/72 (Table 15), with the highest-scoring construct at 3.5/18.0 for Functionality. The user interface was non-existent, buttons were simply crammed under each other, making the graph incredibly difficult to read. Some words were left in French such as “effacer”, meaning “to erase”, making it difficult for the raters to operate efficiently. No reminders were present but readings could be inputted in offline mode since no user profile was offered to save results to the cloud.

Table 10: Scores for “Asthma Tracker” V2.0.1, by Kantonsspital Baselland (iOS, rated August 2016)

Construct	Variable	ACDC Survey Questions	Rater 1	Rater 2	Rater 3	Original -> Adjusted ICC	Original -> Adjusted Total
Engagement	Gamification	Contains gaming principles (such as digital rewards, prizes, leaderboards, badges, aggregated readings or competitions)	0.0	0.0	0.0		
	Customisation	Permits customisation of features (e.g. sound, content, notifications	0.0	0.0	0.0		
	Interactivity	Allows free-text reflections alongside clinical data	0.0	0.0	0.0		
	Engagement through use of plug-ins	Connects with a peripheral device	0.0	0.0	0.5 -> 0.0[1]		
	Self-awareness	Encourages user to develop self-reflection and/or increased self-awareness	0.5	0.0 -> 0.5	0.5		
	Positive behaviour change	Encourages positive self-care practices e.g. using reminders, tips or social influences?	0.0	0.5	0.5		
	Subtotal		0.5	0.5 -> 1.0	1.5 -> 1.0	0.52 -> 0.91	2.5
Functionality	Health warnings	Produces warnings about, or highlights, out-of-range readings	0.0	0.0	0.0		
	Feedback	Provides tactile, visual and/or sound feedback	0.0	0.0	0.5		
	Structural navigation	Facilitates sequential/appropriate navigation	0.5	0.5	0.0		
	Intuitive design	Presents intuitive use e.g. identifiable data input fields, intuitive symbols, generous touch areas	0.5	0.5	0.0		
	Connection to health services	Sends or connects data to another service	1.0	0.5	0.5		

	Performance power	Responds to app features (functions) and components (buttons/menus)	1.0	0.5	1.0		
	Subtotal		3.0	2.0	2.0	0.75	7.0
Ease of Use	Holistic usability	Captures self-management tasks easily in a single app	0.5	1.0	0.0		
	Automation	Facilitates automation of tasks e.g. pre-populated fields, suggestions based on inputs, management of medical appointments, automated customer service	0.0	0.0	0.0		
	Medical and technical jargon	Omits confusing (medical and/or technology) jargon	1.0	1.0	0.0		
	User profile setup	Provides easy setup of user profile, e.g. option to login via social media account	0.5	0.0	0.0		
	Offline mode	Operates core functionality in offline mode	1.0	1.0	1.0		
	Reminders	Enables users to set reminders	0.5	0.5	0.0		
	Subtotal		3.5	3.5	1.0	0.79	8.0
Information Management	Statistics	Permits analysis of clinical data e.g. produces statistics, graphs	0.5	0.5	1.0		
	Privacy and data security	Allows secure data input and export e.g. password management, encryption, privacy statement, cloud backup	0.0	0.0	0.5		
	Quality and accurate information	Accepts and displays correct, relevant information	0.0	0.0	0.5		
	Quantity of information	Offers concise but still comprehensive information	0.0	0.0	0.0		
	Visual information	Illustrates clear and logical charts, graphs, images, videos etc	0.5	0.5	0.5		

	Credibility	Presents credible logo and cites research	0.0	0.0	0.0		
	Subtotal		1.0	1.0	2.5	0.89	4.5
Total			**8.0**	**7.0 -> 7.5**	**7.0 -> 6.5**		**22.0/72.0**

[1] Shaded cells indicate moderation for ICC values <0.7

Table 11: Scores for Asthma Tick V1.2.0, by Shaunak Kale (Android, rated August 2016)

Construct	Variable	ACDC Survey Questions	Rater 1	Rater 2	Rater 3	Original -> Adjusted ICC	Original -> Adjusted Total
Engagement	Gamification	Contains gaming principles (such as digital rewards, prizes, leaderboards, badges, aggregated readings or competitions)	0.0	0.0	0.0		
	Customisation	Permits customisation of features (e.g. sound, content, notifications	0.0	0.0	0.0		
	Interactivity	Allows free-text reflections alongside clinical data	0.5	0.5	0.5		
	Engagement through use of plug-ins	Connects with a peripheral device	0.0	0.0	0.0		
	Self-awareness	Encourages user to develop self-reflection and/or increased self-awareness	0.0	0.0	0.0		
	Positive behaviour change	Encourages positive self-care practices e.g. using reminders, tips or social influences?	0.0	0.0	0.0		
	Subtotal		0.5	0.5	0.5	1.00	1.5
Functionality	Health warnings	Produces warnings about, or highlights, out-of-range readings	0.0	0.0	0.0		
	Feedback	Provides tactile, visual and/or sound feedback	0.0	0.5	0.0		
	Structural navigation	Facilitates sequential/appropriate navigation	0.0	0.5	0.5		

	Intuitive design	Presents intuitive use e.g. identifiable data input fields, intuitive symbols, generous touch areas	0.0	0.5	0.5		
	Connection to health services	Sends or connects data to another service	0.5	0.5	0.5		
	Performance power	Responds to app features (functions) and components (buttons/menus)	0.5	1.0	0.5		
	Subtotal		1.0	3.0	2.0	0.80	6.0
Ease of Use	Holistic usability	Captures self-management tasks easily in a single app	0.0	0.0	0.0		
	Automation	Facilitates automation of tasks e.g. pre-populated fields, suggestions based on inputs, management of medical appointments, automated customer service	0.5	0.0	0.0		
	Medical and technical jargon	Omits confusing (medical and/or technology) jargon	1.0	1.0	1.0		
	User profile setup	Provides easy setup of user profile, e.g. option to login via social media account	0.0	0.0	0.0		
	Offline mode	Operates core functionality in offline mode	1.0	1.0	0.5		
	Reminders	Enables users to set reminders	0.0	0.0	0.0		
	Subtotal		2.5	2.0	1.5	0.88	6.0
Information Management	Statistics	Permits analysis of clinical data e.g. produces statistics, graphs	0.0	0.0	0.0		
	Privacy and data security	Allows secure data input and export e.g. password management, encryption, privacy statement, cloud backup	0.0	0.0	0.0		
	Quality and accurate information	Accepts and displays correct, relevant information	0.5	0.5	0.0 -> 0.5[1]		
	Quantity of information	Offers concise but still comprehensive information	0.5 -> 0.0	0.0	0.0		

	Visual information	Illustrates clear and logical charts, graphs, images, videos etc	0.5	0.0	0.0		
	Credibility	Presents credible logo and cites research	0.0	0.0	0.0		
	Subtotal		1.5 -> 1.0	0.5	0.0 -> 0.5	0.45 -> 0.89	2.0
Total			**5.5 -> 4.0**	**6.0**	**4.0 -> 4.5**		**15.5/72.0**

[1] Shaded cells indicate moderation for ICC values <0.7

Table 12: Scores for "AMS Asthma" V1.1, by Qurasoft GmbH (Android, rated August 2016)

Construct	Variable	ACDC Survey Questions	Rater 1	Rater 2	Rater 3	Original -> Adjusted ICC	Original -> Adjusted Total
Engagement	Gamification	Contains gaming principles (such as digital rewards, prizes, leaderboards, badges, aggregated readings or competitions)	0.0	0.0	0.0		
	Customisation	Permits customisation of features (e.g. sound, content, notifications	0.0	0.0	0.0		
	Interactivity	Allows free-text reflections alongside clinical data	0.5	0.5	0.5		
	Engagement through use of plug-ins	Connects with a peripheral device	0.5	1.0	0.0		
	Self-awareness	Encourages user to develop self-reflection and/or increased self-awareness	0.0	0.5	0.5		
	Positive behaviour change	Encourages positive self-care practices e.g. using reminders, tips or social influences?	0.0	0.0	0.0		
	Subtotal		1.0	2.0	1.0	0.71	4.0

Functionality	Health warnings	Produces warnings about, or highlights, out-of-range readings	0.0 -> 0.5[1]	0.0 -> 0.5	0.5		
	Feedback	Provides tactile, visual and/or sound feedback	0.0	0.0	0.0		
	Structural navigation	Facilitates sequential/appropriate navigation	0.0 -> 0.5	0.5	0.5		
	Intuitive design	Presents intuitive use e.g. identifiable data input fields, intuitive symbols, generous touch areas	0.5	0.5	0.5		
	Connection to health services	Sends or connects data to another service	0.5	0.5	0.0 -> 0.5		
	Performance power	Responds to app features (functions) and components (buttons/menus)	0.5	1.0	0.5		
	Subtotal		1.5 -> 2.5	2.5 -> 3.0	2.0 -> 2.5	0.65 -> 0.91	6.0 -> 8.0
Ease of Use	Holistic usability	Captures self-management tasks easily in a single app	0.5	0.0	1.0		
	Automation	Facilitates automation of tasks e.g. pre-populated fields, suggestions based on inputs, management of medical appointments, automated customer service	0.0	0.0	0.0		
	Medical and technical jargon	Omits confusing (medical and/or technology) jargon	1.0	0.0	1.0		
	User profile setup	Provides easy setup of user profile, e.g. option to login via social media account	0.5	0.5	0.5		
	Offline mode	Operates core functionality in offline mode	1.0	1.0	0.5		
	Reminders	Enables users to set reminders	0.0	0.0	0.0		
	Subtotal		3.0	1.5	3.0	0.70	7.5

Information Management	Statistics	Permits analysis of clinical data e.g. produces statistics, graphs	0.5	0.5	0.5		
	Privacy and data security	Allows secure data input and export e.g. password management, encryption, privacy statement, cloud backup	0.0	0.0	0.0		
	Quality and accurate information	Accepts and displays correct, relevant information	0.5	0.5	0.0		
	Quantity of information	Offers concise but still comprehensive information	0.5	0.0	0.0		
	Visual information	Illustrates clear and logical charts, graphs, images, videos etc	0.5	0.5	0.5		
	Credibility	Presents credible logo and cites research	0.0	0.0	0.0		
	Subtotal		2.0	1.5	1.0	0.84	4.5
Total			**7.5 -> 8.5**	**7.5 -> 8.0**	**7.0 -> 7.5**		**22.0 -> 24.0/72.0**

[1] Shaded cells indicate moderation for ICC values <0.7

Table 13: Scores for "AsthmaMD" V1.7, by AsthmaMD (Android, rated August 2016)

Construct	**Variable**	**ACDC Survey Questions**	**Rater 1**	**Rater 2**	**Rater 3**	**Original -> Adjusted ICC**	**Original -> Adjusted Total**
Engagement	Gamification	Contains gaming principles (such as digital rewards, prizes, leaderboards, badges, aggregated readings or competitions)	0.0	0.0	0.0		
	Customisation	Permits customisation of features (e.g. sound, content, notifications	1.0	1.0	0.0		

	Interactivity	Allows free-text reflections alongside clinical data	1.0	1.0	0.5		
	Engagement through use of plug-ins	Connects with a peripheral device	0.0	0.0	0.0		
	Self-awareness	Encourages user to develop self-reflection and/or increased self-awareness	1.0	1.0	0.5		
	Positive behaviour change	Encourages positive self-care practices e.g. using reminders, tips or social influences?	1.0	0.5	0.5		
	Subtotal		4.0	3.5	1.5	0.87	9.0
Functionality	Health warnings	Produces warnings about, or highlights, out-of-range readings	0.5	0.5	0.5		
	Feedback	Provides tactile, visual and/or sound feedback	0.0 -> 0.5[1]	0.5	0.5		
	Structural navigation	Facilitates sequential/appropriate navigation	0.5	1.0 -> 0.5	0.5		
	Intuitive design	Presents intuitive use e.g. identifiable data input fields, intuitive symbols, generous touch areas	1.0	1.0 -> 0.5	0.5		
	Connection to health services	Sends or connects data to another service	1.0	0.5 -> 1.0	0.5 -> 1.0		
	Performance power	Responds to app features (functions) and components (buttons/menus)	1.0	1.0	0.5		
	Subtotal		4.0 -> 4.5	4.5 -> 4.0	3.0 -> 3.5	0.44 -> 0.81	11.5 -> 12.0
Ease of Use	Holistic usability	Captures self-management tasks easily in a single app	0.5	1.0	1.0		
	Automation	Facilitates automation of tasks e.g. pre-populated fields, suggestions based on inputs, management of medical appointments, automated customer service	0.5	0.0	0.0		

	Medical and technical jargon	Omits confusing (medical and/or technology) jargon	1.0	1.0	1.0		
	User profile setup	Provides easy setup of user profile, e.g. option to login via social media account	0.5	1.0	0.5		
	Offline mode	Operates core functionality in offline mode	1.0	1.0	0.5		
	Reminders	Enables users to set reminders	0.5	1.0	0.5		
	Subtotal		4.0	5.0	3.5	0.74	12.5
Information Management	Statistics	Permits analysis of clinical data e.g. produces statistics, graphs	0.5	0.5	0.5		
	Privacy and data security	Allows secure data input and export e.g. password management, encryption, privacy statement, cloud backup	1.0	1.0	0.5 -> 1.0		
	Quality and accurate information	Accepts and displays correct, relevant information	1.0	1.0	0.5		
	Quantity of information	Offers concise but still comprehensive information	1.0	1.0	0.5 -> 1.0		
	Visual information	Illustrates clear and logical charts, graphs, images, videos etc	1.0	1.0	0.5		
	Credibility	Presents credible logo and cites research	0.0	0.5	0.5		
	Subtotal		4.5	5.0	3.0 -> 4.0	0.68 -> 0.81	12.5 -> 13.5
Total			**16.5 -> 17.0**	**18.0 -> 17.5**	**11.0 -> 12.5**		**45.5 -> 47.0/72.0**

[1] Shaded cells indicate moderation for ICC values <0.7

Table 14: Scores for "Peak Flow" V1.2, by Ben Hills (Android, rated August 2016)

Construct	Variable	ACDC Survey Questions	Rater 1	Rater 2	Rater 3	Original -> Adjusted ICC	Original -> Adjusted Total
Engagement	Gamification	Contains gaming principles (such as digital rewards, prizes, leaderboards, badges, aggregated readings or competitions)	0.0	0.0	0.0		
	Customisation	Permits customisation of features (e.g. sound, content, notifications	0.5	1.0 -> 0.5[1]	0.0 -> 0.5		
	Interactivity	Allows free-text reflections alongside clinical data	0.0 -> 0.5	0.5	0.5		
	Engagement through use of plug-ins	Connects with a peripheral device	0.0	0.0	0.0		
	Self-awareness	Encourages user to develop self-reflection and/or increased self-awareness	0.0	0.5	0.0		
	Positive behaviour change	Encourages positive self-care practices e.g. using reminders, tips or social influences?	0.0	0.0	0.0		
	Subtotal		0.5 -> 1.0	2.0 -> 1.5	0.5 -> 1.0	0.56 -> 0.92	3.0 -> 3.5
Functionality	Health warnings	Produces warnings about, or highlights, out-of-range readings	0.5	0.5	0.5		
	Feedback	Provides tactile, visual and/or sound feedback	0.0	0.0	0.0		
	Structural navigation	Facilitates sequential/appropriate navigation	0.0	1.0	0.5		
	Intuitive design	Presents intuitive use e.g. identifiable data input fields, intuitive symbols, generous touch areas	0.5	1.0	0.5		
	Connection to health services	Sends or connects data to another service	0.5	1.0	0.5		

	Performance power	Responds to app features (functions) and components (buttons/menus)	0.5	1.0	0.5		
	Subtotal		2.0	4.5	2.5	0.79	9.0
Ease of Use	Holistic usability	Captures self-management tasks easily in a single app	0.0	0.0	1.0		
	Automation	Facilitates automation of tasks e.g. pre-populated fields, suggestions based on inputs, management of medical appointments, automated customer service	0.0	0.0	0.0		
	Medical and technical jargon	Omits confusing (medical and/or technology) jargon	1.0	1.0	1.0		
	User profile setup	Provides easy setup of user profile, e.g. option to login via social media account	0.0	0.0	0.0		
	Offline mode	Operates core functionality in offline mode	1.0	1.0	0.5		
	Reminders	Enables users to set reminders	0.0	0.0	0.0		
	Subtotal		2.0	2.0	2.5	0.87	6.5
Information Management	Statistics	Permits analysis of clinical data e.g. produces statistics, graphs	0.5	0.5	0.0		
	Privacy and data security	Allows secure data input and export e.g. password management, encryption, privacy statement, cloud backup	0.0	0.0	0.0		
	Quality and accurate information	Accepts and displays correct, relevant information	0.5	0.0	0.0		
	Quantity of information	Offers concise but still comprehensive information	0.5	0.0	0.0		
	Visual information	Illustrates clear and logical charts, graphs, images, videos etc	0.5	1.0	1.0		
	Credibility	Presents credible logo and cites research	0.0	0.0	0.0		
	Subtotal		2.0	1.5	1.0	0.80	4.5

Total			6.0 -> 6.5	7.5 -> 8.0	6.5 -> 6.0		20.0 -> 20.5/72.0

[1] Shaded cells indicate moderation for ICC values <0.7

Table 15: Scores for “myPeakFlow” V1.0.5, by GestureDevelop (Android, rated August 2016)

Construct	Variable	ACDC Survey Questions	Rater 1	Rater 2	Rater 3	Original -> Adjusted ICC	Original -> Adjusted Total
Engagement	Gamification	Contains gaming principles (such as digital rewards, prizes, leaderboards, badges, aggregated readings or competitions)	0.0	0.0	0.0		
	Customisation	Permits customisation of features (e.g. sound, content, notifications	0.0	0.0	0.0		
	Interactivity	Allows free-text reflections alongside clinical data	0.0	0.0	0.0		
	Engagement through use of plug-ins	Connects with a peripheral device	0.0	0.0	0.0		
	Self-awareness	Encourages user to develop self-reflection and/or increased self-awareness	0.0	0.0	0.0		
	Positive behaviour change	Encourages positive self-care practices e.g. using reminders, tips or social influences?	0.0	0.0	0.0		
	Subtotal		0.0	0.0	0.0	1.00	0.0
Functionality	Health warnings	Produces warnings about, or highlights, out-of-range readings	0.5	0.5	0.5		
	Feedback	Provides tactile, visual and/or sound feedback	0.0	0.0	0.0		
	Structural navigation	Facilitates sequential/appropriate navigation	0.0	0.0	0.0		

	Intuitive design	Presents intuitive use e.g. identifiable data input fields, intuitive symbols, generous touch areas	0.0	0.5	0.0		
	Connection to health services	Sends or connects data to another service	0.0	0.0	0.0		
	Performance power	Responds to app features (functions) and components (buttons/menus)	1.0 -> 0.5[1]	0.5	0.0 -> 0.5		
	Subtotal		1.5 -> 1.0	1.50	0.5 -> 1.0	0.69 -> 0.92	3.5
Ease of Use	Holistic usability	Captures self-management tasks easily in a single app	0.0	0.5	0.0		
	Automation	Facilitates automation of tasks e.g. pre-populated fields, suggestions based on inputs, management of medical appointments, automated customer service	0.0	0.0	0.0		
	Medical and technical jargon	Omits confusing (medical and/or technology) jargon	1.0	1.0	0.5		
	User profile setup	Provides easy setup of user profile, e.g. option to login via social media account	0.0	0.0	0.5		
	Offline mode	Operates core functionality in offline mode	1.0	0.5	1.0		
	Reminders	Enables users to set reminders	0.0	0.0	0.0		
	Subtotal		2.0	2.0	2.0	0.86	6.0
Information Management	Statistics	Permits analysis of clinical data e.g. produces statistics, graphs	0.0	0.5 -> 0.0	0.5 -> 0.0		
	Privacy and data security	Allows secure data input and export e.g. password management, encryption, privacy statement, cloud backup	0.0	0.0	0.0		
	Quality and accurate information	Accepts and displays correct, relevant information	1.0 -> 0.5	0.0	0.5		
	Quantity of information	Offers concise but still comprehensive information	0.0	0.0	0.0		

	Visual information	Illustrates clear and logical charts, graphs, images, videos etc	0.5 -> 0.0	0.0	0.0		
	Credibility	Presents credible logo and cites research	0.0	0.0	0.0		
	Subtotal		1.5 -> 0.5	0.5 -> 0.0	1.0 -> 0.5	0.44 -> 0.75	3.0 -> 1.0
Total			**5.0 -> 3.5**	**4.0 -> 3.5**	**3.5**		**12.0 -> 10.5/72.0**

[1] Shaded cells indicate moderation for ICC values <0.7

Table 12 presents a summary of the score of each rated app, with the highest score being 47.0 and lowest 10.5 out of a possible 72.

Table 16: Summary of Rated App Scores

App Name	**Version***	**Platform**	**Score (out of 72.0)**	**Mode of Rating****
AsthmaMD"	1.7	Android	47.0	Individual
"Asthma Patient Companion"	2.26.8	iOS	34.5	Consensus
"Peak Flow Manager"	1.51	Android	30.0	Consensus
"Asthma Coach"	1.0.1	iOS	28.5	Consensus
"AMS Asthma"	1.1	Android	24.0	Individual
"Asthma Tracker"	2.0.1	iOS	22.0	Individual
"Peak Flow"	1.2	Android	20.5	Individual
"Asthma Plot"	1.0	Android	19.5	Consensus
"Asthma Tick"	1.2.0	Android	15.5	Individual
"myPeakFlow"	1.0.005	Android	10.5	Individual

*All apps were rated between 11 July 2016 and 04 August 2016

**'Individual' = three raters independently with a moderation meeting where required; 'Consensus' = single meeting of three raters

Analysis of the change of scores during moderation revealed rater 1 conceded eight times, rater 2 conceded seven times, and rater 3 conceded nine times out of 72 scores. Such analysis has not been reported in similar health app usability studies.

4.6 Discussion

4.6.1 Adequacy of the Protocol

Overall, the ACDC protocol was found to be effective for the purposes of identifying and assessing asthma self-management apps for their overall quality and suitability for use in clinical settings. The following section details the strengths and limitations of the protocol, with suggestions for its future application. This section is structured according to the three phases described in the published version of the protocol.[110]

The use of a PRISMA-inspired flow diagram[110] as a shortlisting process for asthma apps was found to be highly effective for filtering hundreds of apps, based on criteria such as relevance, provision of clinical management and cost. This process generated a shortlist of 14 apps to assess for quality and suitability for use in clinical settings.

4.6.1.1 Shortlisting Process

The number of shortlisting steps in the PRISMA-inspired flow diagram was optimal to achieve manageable and economical filtering of apps for asthma self-management. Any fewer shortlisting steps could impact practicality and yield an unmanageable number of shortlisted apps. Proportionally, 1/18 iOS apps and 1/31 Android apps were retained using this method, and it was noted the Google Play™ store search yielded fewer relevant apps than the iOS App Store®. Compared to other health app shortlisting processes,[145,146] the filtering appeared efficient and more structured. This is likely since publishing via the Google Play™ store requires a comparatively less restrictive submission process and less developer guidance is provided.[139] Additionally, the protocol should be trialled with apps for other chronic disease states (such as hypertension) to determine its robustness.

In cases where shortlisting does not yield a manageable number of apps to rate, researchers and clinicians have other options, depending on their situation. Additional condition(s) – e.g. country of origin – can be added to the PRISMA-inspired diagram if already-shortlisted apps are not representative of the desired function. Some clinical management apps only entail one main feature such as data input management, compared to another clinical management app whose primary functionality may be data export or referral management. Therefore, if researchers are searching for a particular style of clinical management app, filtering by dominant clinical management feature is useful.

Fewer shortlisting steps than those published[110] is unlikely to work as effectively when determining which app is suitable as an adjunct to (or as) a clinical intervention. No PRISMA-inspired flow modifications were deemed necessary for the asthma app shortlisting process. The application of this protocol to identify apps for self-management in other disease states has not yet been established, and warrants further research.

4.6.1.2 Trialling Apps

A dummy patient profile provides consistency when trialling data entry and standardised responses to input variables required by apps, as recognised by previous health app usability studies[101,147] and supported by experiences in this first trial of the ACDC. Providing a comprehensive dummy patient profile was necessary to meet the needs of a wide variety of apps, and to allow comparison between apps. The current research recommends that, as a minimum, every dummy profile should include the following details: self-monitored readings and their date/time, medication dosage, frequency and data entry-related notes such as ‘post-exercise reading’ or ‘nervous pre-interview reading’. An iterative process was applied to evolution of the current dummy profile; as each app was trialled, the profile was supplemented with hypothetical data used to progress through the app. As the dummy profile was untrialled and expected to require embellishment, it was logical for the consensus rating of apps to commence before raters proceeded independently through the remaining apps. The raters could devise suitable data requested of apps during the consensus assessment, and hence improve the dummy profile. Over the course of shortlisting 360 apps and trialling 14 apps, the following variables were added to the profile: rater's email address to test reporting functions, more elaborate triggers, more comprehensive profiles and further medication details. After trialling 14 asthma apps, only three iOS apps and seven Android apps were rated due to access issues outlined in Section 5.6.1.1. Other health app studies[148,149] highlighted that dosage frequency and international drug naming conventions required consideration of the local market or geography.

It is important to acknowledge merely assigning an app to a consumer without engagement from a healthcare professional does not ensure sustained interaction and data entry by the consumer. Many assessed apps did not appear to offer sustained engagement in one's self-care practices.

Entering a week's worth of realistic in-range peak flow readings, followed by a week representing poor control of the chronic condition seemed plausible to test the capacity of an app to provide out-of-range alerts. No previous studies had reported this approach. Whilst this approach worked effectively for most apps, some did not allow backdating of clinical readings, meaning readings required input prospectively over two weeks. These limitations did not significantly delay the rating process, but required vigilance amongst raters to enter daily readings. Disallowing backdating of self-monitored data can be inefficient in a consumer's use of an app, as some users handwrite readings before input of the data,[65] and could benefit from immediate feedback if these data were able to be entered. Limiting data entry to prospective readings means the app cannot readily develop a 'history' for that user, which may compromise persistence by the user of the app for self-monitoring. Immediate feedback about progress, based on back-entered readings, may provide motivation to continue self-monitoring; additionally, patient selection of treatment options becomes more informed through individualised self-monitoring.[150] Moreover, consumers becoming more informed has been found to alleviate reoccurring daily challenges.[151] Of note, one of the apps requiring prospective input ("Asthma Tracker" on iOS) provided a daily banner notification, reminding consumers to enter time-sensitive readings. The reminder was initially useful, but the repetition became irritating. There are other ways to ensure the correct date is associated with (retrospective) data input, such as display of a confirmation message or highlighting the present day's readings.

It was deemed practical for a rater to initially spend five to 10 minutes navigating each app's features before rating the app using the ACDC. Dummy data could be inputted at this stage and re-examined during the rating stage. This enabled efficient transition through the ACDC questionnaire once rating commenced.

4.6.2 The Scoring Protocol

Qualtrics provided a reliable and flexible platform to devise the ACDC questions and analyse responses. Qualtrics' data export feature, used with SPSS™ Version 23 (IBM Corp., Armonk, NY; 2015), enabled seamless transition in preparation for data analysis. This approach offered an advancement over a similar health app usability study that used an Excel™ spreadsheet to collate scores.[99]

The three-point scoring system from 0.0 to 1.0 for each variable that was used in this study can affect ICC calculations due to the incremental differences between each score. Based on checklist wording, a score of 0.0 is required to denote a response lacking a certain quality. A three-point scale anchored by scores of 1, 2 and 3, instead of 0.0, 0.5 and 1.0, was trialled, and was confirmed to achieve greater consistency between raters, indicated by higher ICC values. As such, the 0.0 to 1.0 graduation in the three-point scale in this study compromised ICC values. The consequence was a relatively high number of subscales that required moderation of scores. However, as designed, the questions in the ACDC require a negative response to carry a null value, rather than 1.

Therefore, an ICC of less than 0.7 to indicate adequate consistency could be considered in future research, on account of the scale increments used. Consequently, less moderation should be required. The MARS study used a cut-off of 0.6 (or 3 out of 5 points) for apps to be deemed 'acceptable'.[99] The level of moderation required for rating of the current cohort of asthma apps was undesirable, but manageable. For medical conditions yielding a significantly larger number of shortlisted apps, the current level of moderation would be unmanageable. Nevertheless, the moderation process was useful to reveal characteristics of the apps, and over time, the need to further moderate may decrease, since the sub-questions should be more easily applied across applications. Another health app study used 0.7 as the ICC cut-off,[101] and a degree of robustness was offered in the present study by applying this value, at least for this initial trial of the ACDC. Further discussion about the moderation process is provided in Section 5.6.3.

A three-point scale is easier to answer than a five-point scale, and therefore is more efficient for rating larger numbers of apps. However, it becomes less efficient if it generates lower ICCs and raters find the need to moderate their scores. Similar health app usability studies by Stoyanov et al.[99] and Hundert et al.[101] used a five-point scale and deemed it suitable for their studies. However, use of a three-point scale, an ordinal level of measurement, in the present study offered simplicity, with a view to the scoring protocol being used across a larger number of apps, and for raters with limited experience with mobile apps. Future studies may formally compare three- and five-point scales to determine their relative efficiency and discriminatory power. As cited in Jacoby et al.,[152] Bendig (1954) and Komorita (1963) identified the “number of response categories” does not correlate with reliability. For this study, this suggests there was no significant loss of reliability by using a three-point scale.

Despite the apparent robustness of the ACDC, it is important to acknowledge that quantifying features and functionality of an app is a research exercise. A consumer or health professional may identify a particular app as appropriate for an intended use (such as simple medication reminders), even if the app scored, or would score, poorly using the ACDC.

4.6.3 Inter-Rater Consistency

Rater 1 was the PhD candidate, who has IT consulting and mobile app design industry experience. Raters 2 and 3 were academics with Pharmacy Practice backgrounds. Rater 2 had experience in asthma self-management research. Rater 3 self-identified as having limited experience in using mobile technologies, which provided a useful balance to the team in terms of identifying usability issues. As a research exercise, the rating panel did not include health consumers. This recognises that an appropriate number of health consumers would participate in the subsequent trial of the app(s), as opposed to the researchers attempting to identify one or more consumers who are representative of all users to participate in the initial screening. Further elaboration is provided in Section 3.4.6. Using all IT professionals or all pharmacists as raters remains untested. It is possible that a team of raters with IT expertise would have generated lower and more objective Information Management ratings. Based on a similar study such as MARS[99] in Queensland, Australia, the raters also constituted an IT professional and Health Science academics. Moreover, using three raters was found to be a practical option in a clinical trial research setting.

Table 17 provides collated raw (unmoderated) average scores across all independently-assessed apps for rater 1, 2 and 3. The range in raw scores is also presented here, spanning from 0.5 to 7.0. This level of pre-moderation variability is manageable, does not suggest more raters are required and is only concerning for “AsthmaMD” because it was one of the first rated individually compared to “Asthma Tracker” which was rated last. Raters 1 and 3 displayed closer scores compared to rater 2. No particular rater demonstrated consistently higher or lower scores than another.

Table 17: Unmoderated Average Scores

Raw, Unmoderated Average App Score	Rater 1	Rater 2	Rater 3	Range
iOS				
”Asthma Tracker”	8.0	7.5	6.5	**1.5**
Android				
”Asthma Tick”	4.0	6.0	4.5	**2.0**
”AMS Asthma”	8.5	8.0	7.5	**1.0**
”AsthmaMD”	17.0	17.5	12.5	**5.0**
”Peak Flow”	6.5	8.0	6.0	**2.0**
”myPeakFlow”	3.5	3.5	3.0	**0**

*All apps were rated between 11 July 2016 and 04 August 2016

**‘Individual’ = three raters independently with a moderation meeting where required; ‘Consensus’ = single meeting of three raters

Consensus assessment of apps familiarises raters as a team with each app’s functionality and features. Such collaboration should reduce variability prior to individual rating. Table 5 (“Peak Flow Manager”) required the least amount of negotiation due to the app’s simplicity and straightforward navigation, with only two raters adjusting scores for the Information Management construct. The present findings suggest application of the ACDC should commence with consensus measurement, prior to rating the rest as individual assessors.

The domains requiring the greatest amount of effort in moderation were Functionality and Information Management, each requiring moderation in three apps out of 10. The Information Management construct was the least expected to require moderation, as many of the variables require objective responses. By contrast, Functionality was expected to be more subjective and therefore generate lower ICC values. One possible reason is the varying level of experience with mobile apps amongst the three raters. This finding of poor interrater reliability among certain constructs is in line with an interrater reliability study, suggesting stringent measures such as complimenting rating scales with a standalone, purpose-built, checklist.[153] Such variations, in conjunction with the primary rating scale, have been utilised in a New Zealand smoking cessation and weight management study.[104]

The variable most commonly associated with a difference of opinion between raters was 'Connection to Health Services' within the Functionality construct. This was due to differences in opinion on what denotes connection to a health service, for example, general data exporting compared with automatic synchronising to a nominated healthcare professional. Therefore, a change in wording may address inconsistencies in interpretation.

During development of the checklist, the Ease of Use construct was subjected to the most re-wording and discussion about definition.
There was no apparent correlation between the amount of moderation required and the overall score for an app. "Peak Flow" represents the app with the highest overall score of all rated apps. Patterns for the remaining apps (Tables 10-15) are inconclusive.

Scoring by consensus enables, indeed *requires*, raters to establish common understanding of the variables and interpretation of the scoring metrics. Consequently, this provides greater confidence, and potentially more consistent scores, when then rating as individuals.

The methods presented here suggest assessment of 10 apps was manageable and did not result in rater fatigue. Up to double this number may require streamlining of the protocol or use of teams of raters; the latter would introduce the need for measurement of inter-panel consistency. Rater fatigue, also referred to as rater drift, can impact results between raters.[154] In one study, three two-hour sessions within a six-hour shift yielded greater rater accuracy and rater consistency compared to two four-hour sessions within an eight-hour shift.[155] The same authors also concluded scoring quality improves after a pause, compared to before a pause. Additionally, rating this number of apps in a random order can be conducted in a single sitting (excluding apps not permitting backdated entries), resulting in greater intra-rater reliability compared with rating a few apps per day. If additional

PRISMA-inspired processes are added and shortlisted apps exceed 20 apps, other options, such as two teams of raters, should be explored.

4.6.4 Reflection on the Shortlisted Apps

Empirical observations of shortlisted apps include:

- Some apps, such as "AsthmaPlot" (Android), do not accept backdated entries, placing onus on daily self-care readings. For some people, it is not always possible to input daily peak flow readings.
- Few apps presented legible graphs; others were either too small or difficult to interpret.
- Medication brand names from the UK and US (e.g. Flovent™) proved confusing for Australian raters, and presumably for Australian health consumers.
- Some apps presented a complex initial display screen, which may be off-putting to health consumers.
- "MyPeakFlow" (from France) did not include all translated words in English; for example 'profil1', instead of 'profile 1' was confusing.
- An app displaying advertising on the bottom section of the screen was unappealing to the three raters.
- Consumer-friendly export file types were not universally provided; XML files can be difficult to interpret by consumers and difficult to open using smartphone applications.
- Siloed, standalone apps with no accompanying products/services generally presented limited functionality, and some lacked elements to support sustained user engagement.
- Although the common traffic-light colour-coding system[156] used in asthma action plans was present in most apps with a graphical module, the colour associated with each entry was not always clear or accurate. For example, a reading of 350 L/min equates to 76%. It was not clear what 76% represented, since the best score was 650 L/min.

The most unsatisfactory app features included:

- Inconsistent saving of inputted data,
- Comical images or sound effects (e.g. inhaler puffs) that could not be disabled,

- Confusing layout, and
- Unconventional navigation, taking the consumer longer to become familiar with features of the app. An example was no central ‘home screen’ function, requiring the user several steps to return to the home screen.

Additionally, several apps presented minimal features, suggesting interest by the user would not be sustained. One health app study has identified self-regulation features relating to feedback and goal-setting can sustain app-interaction and improve consumer engagement.[157]

“AsthmaMD”, released in 2015 from California, was the highest-rated app, with a score of 47/72. The peripheral devices for “AsthmaMD” are available commercially through Amazon, and at the time of writing, the app was in medical use by its founder at his private practice in California. Apps actively used in clinical settings have greater onus to meet consumer requirements than commercial apps which seek funding from in-app advertising and *ad hoc* purchases such as for in-depth Pro app versions. Strengths of “AsthmaMD” also included files opening as comma-separated values, professional-looking layout and research collaboration via a Californian university research grant. There was some correlation within consumers’ text-based reviews in the respective app stores, but it was not a focus of this study design. Despite these strengths, the total score for this app was 10 points lower than the arbitrary 80% cut-off score of 57.6 to be suitable for use in an Australian clinical trial. However, apps with scores over 70% (47/72.0) of the maximum may be suitable for personal, self-monitored health use.

The lowest-rated app was “myPeakFlow”, with a score of 10.5/72. This app lacked many basic features and was deemed impractical to facilitate self-care for consumers with asthma. Such apps are not suitable for clinical trial use, and would likely create unnecessary workload due to their limited functionality.

An ideal asthma app would not only allow peak flow and spirometry entries, but also data extraction via email, notification of critical entries to a next of kin and nominated healthcare professional, integrated statistical features to map health across weeks/months, and the ability to backdate entries. Layout-wise, consumers should be comfortable navigating through various aspects without hindrance or asking another person.

Gamification was not observed in the shortlisted asthma apps, but might encourage persistence and engagement in use of apps.[99,158,159]

In rating apps, it became apparent apps with a commercial background, such as selling an accompanying peak flow meter, have greater onus to deliver holistic, comprehensive consumer experience, and rated the highest of the shortlisted apps. Apps with a commercial affiliation, such as "AsthmaMD", should manage ethical dilemmas in a clinical trial setting. Rated Android apps such as "myPeakFlow" by GestureDevelop and "Peak Flow" by Ben Hills are prime examples of non-commercial apps where no advertising or purchases confront the user. The probability of apps with commercial influences is increased should apps be manufactured or supported by pharmaceutical manufacturers promoting a particular asthma (or hypertensive) medication. One variable, "Credibility" (Q5.6), recognises certification by independent professional organisations, research institutes or bodies. Of note, the National Asthma Council Australia has created the "AsthmaBuddy" app for iOS devices, released 09 August 2012, and has not promoted other asthma apps on their website. The Android version is no longer available on the Google Play™ store. "AsthmaBuddy" did not appear in the present shortlist, because no clinical management function was present and it had not been updated within the previous 12 months. The primary function is to deliver a digital asthma action plan.

4.6.5 Conclusion

In conclusion, the ACDC was designed to identify, assess and rate apps that may be suitable for clinical usage. Out of all rated apps, only "AsthmaMD", with a score of 47/72, was the closest app meeting the arbitrary 80% of the maximum score required for this purpose.

During evaluation of the features and capability of the shortlisted apps, it became apparent there were few commonalities between apps. Some apps merely facilitated data entry; fewer offered more comprehensive health management. The purpose of rating apps is to assist clinicians and researchers to identify one or more theoretically-backed, consumer-friendly and medically-functional health apps to facilitate consumers' self-care. Without validation of the choice of apps, clinical trials incorporating apps for self-monitoring can be jeopardised. Consequently, developers can benefit from validating app modules and functionality, which is important to facilitate self-care of a chronic condition.

Furthermore, this checklist demonstrated significant room for improvement for all apps. Whether these improvements could be resourced by the developers remains unknown. Moreover, this research calls for coordinated funding and endorsement by a professional disease support organisation to develop and trial an app to incorporate the features that are identified in the ACDC and lacking in marketed apps. No shortlisted apps were deemed sufficiently robust and usable to recommend for further trial by consumers. Consequently, consumers should be aware that not all health apps have the necessary functionality to facilitate self-care of their chronic condition. The next stage involves a sub-study with another chronic condition requiring objective (rather than subjective) measurement to test reliability and robustness of the ACDC.

5 CHAPTER 5 Results: Validation of Hypertension Management Apps (Sub-Study 2)

5.1 Preface

This chapter presents the results of the ACDC protocol, further validated with sub-study 2: hypertension apps. Research Objective 3b is addressed in this chapter, namely: "Validation of the protocol using another chronic condition (hypertension)."

Similar to the asthma sub-study, inclusion criteria comprised removal of duplicates, non-English apps, paid and apps not updated within 12 months from date of shortlisting. The remaining apps were again initially separated by core function such as clinical hypertension management, eBook, exercise, novelty/entertainment, availability in Australia, journal/conference-related and whether hypertension involves the core function of the app. All hypertension apps were rated between 08 June 2017 and 13 July 2017.

5.2 Introduction: Re-validation of the ACDC in another Disease State

Following from the asthma sub-study, this second sub-study ensures robustness of the ACDC by applying it to another disease state, namely hypertension, which again is self-managed using objective data that health consumers can generate. Hypertension was selected, since self-management can incorporate self-monitoring that generates objective data. The emergence of Bluetooth® Low-Energy (BLE)-enabled peripherals such as glucose/heart rate monitors and wearables such as FitBit™ and Apple Watch™ in Australia[160] also suggest a future involving increased self-monitoring by a broader sector of the population, with data transfer to health professionals.

In seeking a second disease state in which to test the ACDC, diabetes was excluded due to published studies on self-management including text messaging,[161] email and text messaging,[162] and use of mobile diabetes apps.[73,163-166] Cancer was also excluded due to its many types, and less relevance to self-monitoring to produce data for monitoring.

5.2.1 Challenges of Hypertension

According to Australia's Heart Foundation, a blood pressure reading of 120/80 is normal, and 140/90 signifies Stage 1 hypertension.[167] It has been estimated that 34% of Australians over 18 years of age have Stage 1 hypertension.[167] Of the 34%, 68% (4.1 million) have hypertension that remains untreated or uncontrolled in nature.[167] Marginally more men present with uncontrolled hypertension than women (24% compared to 22% in 2015).[167] The highest prevalence is in the over 75 years bracket, with 47% of these individuals presenting uncontrolled hypertension.[168] According to the Australian Bureau of Statistics, Indigenous Australians are also disposed to hypertensive symptoms, affecting 25% of the Indigenous population.[169]

Self-monitoring of hypertension is particularly valuable when hypertension is asymptomatic, because if left uncontrolled, hypertension can have life-threatening risks. Uncontrolled hypertension is a precursor for a range of conditions such as "myocardial infarction, chronic kidney disease, stroke, heart failure and premature death."[170]

5.2.2 Availability of Blood Pressure Monitors for Home/Lay Use

In Australia, there is an emerging array of BLE-enabled blood pressure monitors available from pharmacies. Blood pressure monitors generally produce a systolic and diastolic blood pressure reading, supplemented by a pulse (heart) rate reading. Examples are iHealth® Feel and Omron® HEM7280T Blood Pressure Monitor, retailing at approximately AU$150[171] and AU$200,[172] respectively. Other Australian electrical retailers offer the Beurer® BM57 Bluetooth® Upper Arm Blood Pressure Monitor for AU$128.[173]
Traditional automotive global positioning system navigation devices such as Garmin® and TomTom® have branched into the wearable fitness market, offering devices with the ability to track heart rate. The future can see blood pressure (systolic and diastolic readings) incorporated into wearables, with synching to smart cuffs and/or interoperability with existing BLE blood pressure monitors. Fitness trackers such as FitBit®, Jawbone® and the Apple Watch™ have also extended their traditional step counter and calorie tracker functions to include continuous tracking of heart rate.[174]

The consumer will benefit from a holistic self-care management solution with the ability to track readings, share data with health professionals, aggregate and tabulate readings and be more informed of trends in their readings than when using standalone, periodic monitoring. Hypertension cuffs synchronised via Bluetooth® correspond with a mobile app to automatically transfer readings. For traditional monitors (sphygmomanometers) with no automatic data transfer, consumers still benefit from transcribing daily readings to observe fluctuations. More information is provided in Section 5.2.3.

5.2.3 Studies in which Hypertension Self-Monitoring has been Evaluated

A number of studies have tested the accuracy and validity of wearable blood pressure monitoring devices, as outlined below.[175,176]

The National Heart Foundation of Australia recommends using a mercury sphygmomanometer, with three readings taken at the brachial artery;[170] this standard is also agreed to internationally.[177] The last two readings are averaged and used as the documented blood pressure reading.[170] The brachial artery is also used when using a gold standard cardiology stethoscope to measure heart rate.[178,179] Blood pressure monitors routinely produce a heart rate reading in addition to systolic and diastolic blood pressure readings. The standards do not mention any recommendation to document the heart rate.

A study into Omron® (HEM-711AC) and a ReliOn® (HEM-741CREL) blood pressure monitors revealed their suitability for use for self-monitoring compared to "auscultation with a stethoscope and aneroid sphygmomanometer."[180] Another study by different authors also indicated minimal difference in pulse (or heart rate) readings between digital and analogue methods, but noted systolic readings are more variable with analogue monitors, compared to digital monitors.

When compared to the gold standard electrocardiogram for measuring arrhythmias and electrical impulses from the heart,[181] two studies have concurred in their findings about errors in heart rate readings produced by wearables, particularly during "moderate to vigorous physical activity."[182,183] For example, Gorny et al. reported Fitbit® readings to only produce half the "moderate to vigorous physical activity" readings accurately, with an average underestimation of 16 beats per minute (bpm) for "moderate to vigorous activity", and cited two papers confirming similar underestimation.[183] A summary of all activities resulted in a 7% underestimation (6 bpm).[183]

For blood pressure monitors without Bluetooth® connectivity, manual data entry of readings into a consumer's smartphone or mobile device can enhance consumers' engagement with their healthcare team and increase their confidence in managing their condition.[184] These factors, however, are largely dependent on the app's conformance to guidelines such as the ACDC to facilitate sustained use and grow with the consumer's needs.[110]

With the evolution of patient autonomy and wearable health technology, it is reasonable to accept and expect self-monitoring by consumers with hypertension. Indeed, one Canadian study provided consumers with a pre-programmed Blackberry® and a Bluetooth®-enabled device to measure blood pressure and heart rate.[185] The increased workload for clinicians when using additional metrics and data was noted as an initial drawback for clinicians.

Review of the literature revealed no published studies in which the quality or usability of hypertension monitoring apps had been assessed. To date, the MARS has not been applied to hypertension apps.[99,106] A 2016 South Korean study of a custom-built hypertension app indicated this type of app should acknowledge and incorporate "clinical practice guidelines" to facilitate self-monitoring. This positively influenced perceived usefulness of the app.[186]

Positive adherence to measuring blood pressure was noted in the Netherlands in a study using an off-the-shelf hypertension monitoring app ("iVitality").[187] In this trial, the 151 participants, with a mean age of 57.3 years, were allocated into two protocols over six months. Group one required systolic and diastolic measurements twice in the morning and twice in the evening over two consecutive days per month. Group 2 required the same measurements, but only twice in the morning and evening for one day. Group 1 demonstrated higher adherence rates.

A systematic review of hypertension self-management using telemedicine uncovered key enablers for remote self-management: cost-effectiveness, convenience and ubiquitous access. Barriers to entry encompassed the difficulty to maintain longitudinal self-care data, added workload and paucity of evidence to support self-monitoring.[188]

5.3 Aims

The aims of this chapter align with aim 2b from the overall aims, namely: [to] "evaluate available health apps for a particular health condition, via critical appraisal of health apps for that condition." Critical appraisal has been conducted by following the ACDC peer-reviewed protocol[110] for the current condition of interest.

5.4 Methods

The methods follow those of the published protocol[110] and its previous application to asthma apps (Chapter 4). Exceptions, specific adaptations and additional steps necessitated in this trial are detailed in the following sections.

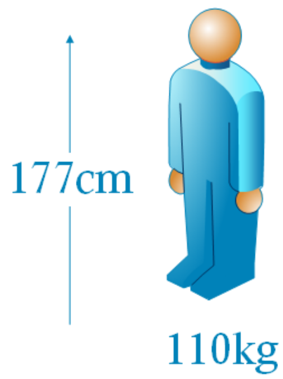
5.4.1 Phase 1: Selection of Apps

As per the asthma sub-study, the custom-designed PRISMA-inspired flow diagram was used to filter hypertension apps available via the App Store® and Android Google Play™ store using the word 'hypertension'. Initial screening of apps in the hypertension sub-study identified apps dedicated to hypertension journals and a hypertension conference. These were eliminated through the addition of another swimlane within the screening flowchart; all other variables were retained.

5.4.2 Phases 2 and 3: Evaluation of Apps

A customised dummy patient profile was again required. The profile was designed to represent characteristics and risk factors typical of a person with hypertension. The resulting profile is presented in Figure 5. The same iOS and Android devices will be used for both the asthma and hypertension trials.

Mr Test Dummy
01.01.1962 (M)



Profile before Updates

- Stressful, sedentary work environment
- High salt intake
- High alcohol consumption
- Heavy smoker
- Appreciates systolic reading between 110 and 130mmHg and diastolic between 70 and 80mmHg is ideal
- Obesity since childhood
- Variable BP control over the past 20 years

Medication:

- Coversyl® (perindopril)
  4mg d (tablet)
  27.05.2010 – 27.05.2040

Assumptions:

- Acceptable blood pressure monitoring technique
- Takes no other medication apart from ibuprofen and paracetamol when required
- To test reporting functions:
  GP: Dr Test Account (use 2nd rater's email)
  NoK: Daughter Dummy (use 3rd rater's email)
- Postcode/ ZIP: [6000]
- City: [Perth, WA]

Profile after Updates

- Caucasian
- Stressful, sedentary work environment
- High salt intake
- High alcohol consumption (2 standard drinks/day, up to 6/sitting)
- Smokes 10 cigarettes a day
- Sleeps 6 hours / day

- Appreciates systolic reading between 110 and 130mmHg and diastolic between 70 and 80mmHg is ideal

- Resting Heart Rate: 85bpm
- Obesity since childhood
- Variable BP control over the past 20 years

Medication:

- Coversyl® (perindopril)
  4mg d (tablet)
  27.05.2010 – 27.05.2040
- Lipitor® (atorvastatin)
  20mg d (tablet)

Assumptions:

- Place of Measurement: right arm (sitting)
- Self-measured readings during the morning
- Acceptable blood pressure monitoring technique
- Takes no other medication apart from ibuprofen and paracetamol when required
- To test reporting functions:
  GP: Dr Test Account (use 2nd rater's email)
  NoK: Daughter Dummy (use 3rd rater's email)
- Postcode/ ZIP: [6000]
- City: [Perth, WA]

Figure 5: Before and After Hypertension Test Dummy Profiles

The same iOS and Android devices were used as for the previous trial. The same three raters undertook "simulated use of the apps" as per the published protocol.[110] Again, two apps per platform were rated by consensus (n=4).

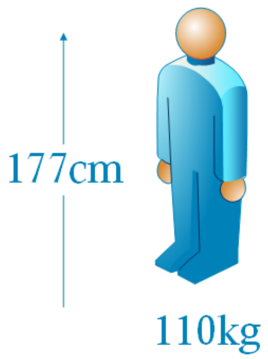
The ACDC was used to rate shortlisted apps as per the published protocol.[110] Again, Qualtrics® was used to capture checklist responses, and SPSS® v24 was utilised for data analysis.

All ACDC variables were represented with a scoring option of 0, 0.5 or 1.0 within constructs labelled "Engagement, Functionality, Ease of Use, and Information Management," as per the ACDC protocol.[110] Subtotals for each construct, and a total score for each app, were again calculated. For the apps rated by consensus (three raters), a 'projected' total (the total of the consensus scores multiplied by three) was presented to enable direct comparison with apps scored by three raters independently, where the sum from each of the raters was totalled. Again, two-way mixed ICC was calculated for each of the four constructs of the ACDC.

5.4.3 Context-Specific Considerations for the Hypertension Sub-Study

Figure 6 illustrates the dummy patient profile before and after familiarisation of the rating panel with shortlisted apps. The dummy profile describes a 55-year-old male with chronic hypertension. The profile was changed during consensus rating to include adjunct therapy with a lipid-lowering agent, resting heart rate, sleep quantity and number of cigarettes smoked daily. The profile was then locked down for individual rating, and no additional features were found to be required during individual rating. "Reliever medication" was omitted from the hypertension dummy profile.

Mr Test Dummy
01.01.1962 (M)



Profile before Updates

- Stressful, sedentary work environment
- High salt intake
- High alcohol consumption
- Heavy smoker
- Appreciates systolic reading between 110 and 130mmHg and diastolic between 70 and 80mmHg is ideal
- Obesity since childhood
- Variable BP control over the past 20 years

Medication:

- Coversyl® (perindopril)
  4mg d (tablet)
  27.05.2010 – 27.05.2040

Assumptions:

- Acceptable blood pressure monitoring technique
- Takes no other medication apart from ibuprofen and paracetamol when required
- To test reporting functions:
  GP: Dr Test Account (use 2nd rater's email)
  NoK: Daughter Dummy (use 3rd rater's email)
- Postcode/ ZIP: [6000]
- City: [Perth, WA]

Profile after Updates

- Caucasian
- Stressful, sedentary work environment
- High salt intake
- High alcohol consumption (2 standard drinks/day, up to 6/sitting)
- Smokes 10 cigarettes a day
- Sleeps 6 hours / day

- Appreciates systolic reading between 110 and 130mmHg and diastolic between 70 and 80mmHg is ideal

- Resting Heart Rate: 85bpm
- Obesity since childhood
- Variable BP control over the past 20 years

Medication:

- Coversyl® (perindopril)
  4mg d (tablet)
  27.05.2010 – 27.05.2040
- Lipitor® (atorvastatin)
  20mg d (tablet)

Assumptions:

- Place of Measurement: right arm (sitting)
- Self-measured readings during the morning
- Acceptable blood pressure monitoring technique
- Takes no other medication apart from ibuprofen and paracetamol when required
- To test reporting functions:
  GP: Dr Test Account (use 2nd rater's email)
  NoK: Daughter Dummy (use 3rd rater's email)
- Postcode/ ZIP: [6000]
- City: [Perth, WA]

Figure 6: Dummy Profile for Testing Hypertension Monitoring Apps (Original vs Modified)

Dummy hypertension values used by the raters for testing the data entry functions in apps are listed in Table 18.

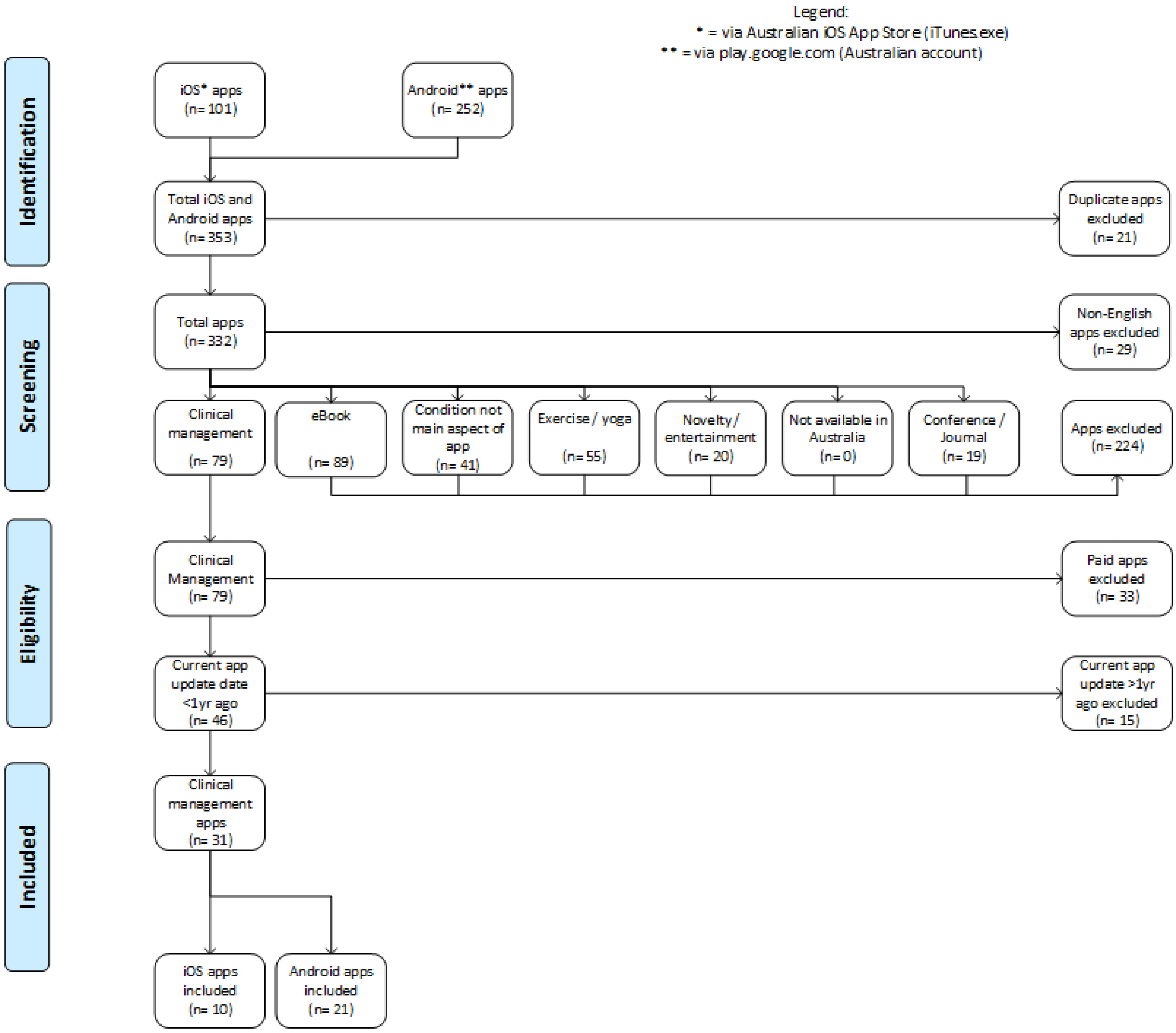
Table 18: Dummy Hypertension Values over a Two-Week Period

Date	**Blood Pressure (systolic/diastolic)**	**Heart Rate**
24.05.2017	128/78	85
25.05.2017	123/78	81
26.05.2017	130/81	86
27.05.2017	124/83	83
28.05.2017	128/79	78
29.05.2017	120/84	80
30.05.2017	118/78	82
Poor Self-Management Week		
31.05.2017	140/90	85
01.06.2017	160/100	86
02.06.2017	180/110	83
03.06.2017	No reading (lapse in daily monitoring)	
04.06.2017	No reading (lapse in daily monitoring)	
05.06.2017	No reading (lapse in daily monitoring)	
06.06.2017	152/104	83

5.5 Results

5.5.1 Shortlisted Hypertension Management Apps

In total, 353 apps for self-management of hypertension (101 Apple and 252 Android) were subjected to the custom-designed shortlisting process. Of these, 21 hypertension apps were duplicated between the two platforms, and the iOS version of each duplicate was retained (Figure 7). Thirty-one shortlisted hypertension apps (10 iOS and 21 Android) from the initial 353 were shortlisted using the flow diagram. 14 shortlisted asthma apps (6 iOS and 8 Android) from the initial 365 were shortlisted using the flow diagram.

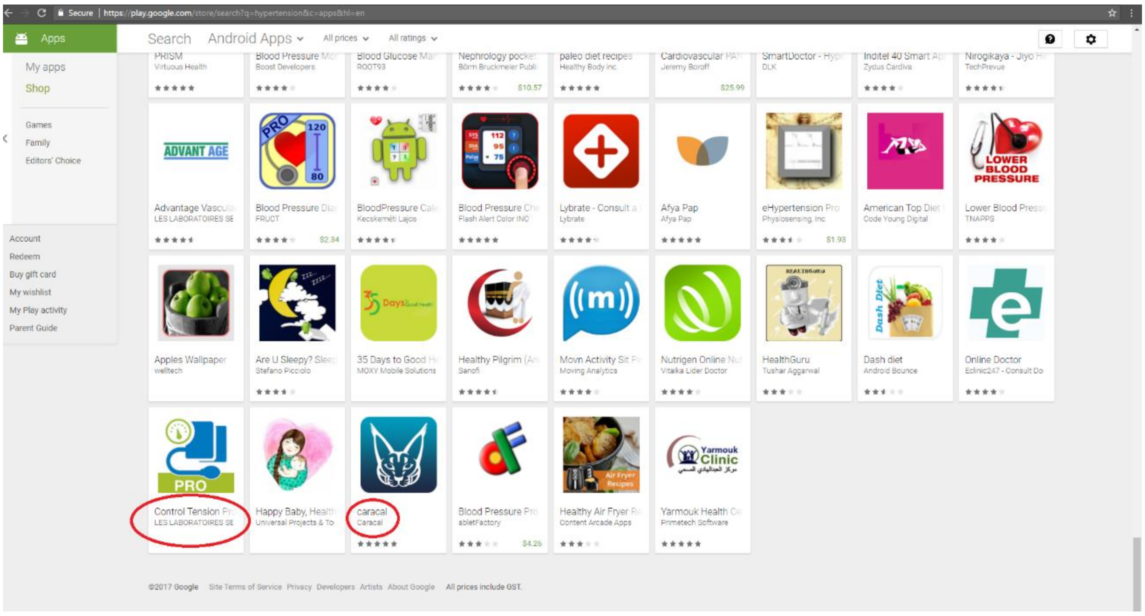


Adapted from:
Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and MetaAnalyses: The PRISMA Statement. PLoS Med 6(6): e1000097. doi:10.1371/journal.pmed1000097

[1] Anderson K, Burford O, Emmerton L. App Chronic Disease Checklist: a method to evaluate mobile apps for chronic disease self-management. JMIR Res Protoc. 2016 [doi:10.2196/resprot.6194]. [Medline: 27815233]

Figure 7: Hypertension App Shortlisting Process using the Published PRISMA-Inspired Flow Diagram[1]

Some limitations were noted in the search results of both platforms. The Android Google Play™ store presented inefficiencies when searching for clinical management apps. For example, two highly relevant hypertension management apps were insufficiently prioritised in the search results, listed in the final six out of 252 apps (Figure 8); this was not an issue in the App Store®.



[1]Apps “Control Tension Pro” and “Caracal” are circled in red

Figure 8: Clinical Management Hypertension Apps Illustrating Useful Clinical Apps in the Final Row

The Android Google Play™ store also identified some apps of questionable relevance to the search term ‘hypertension’ (Figure 9), for example, “African Drums Meditation” to combat hypertension through musical rhythms, a “Guide to High Risk Pregnancy” app, and diet apps such as “Diet Dash Pro”.

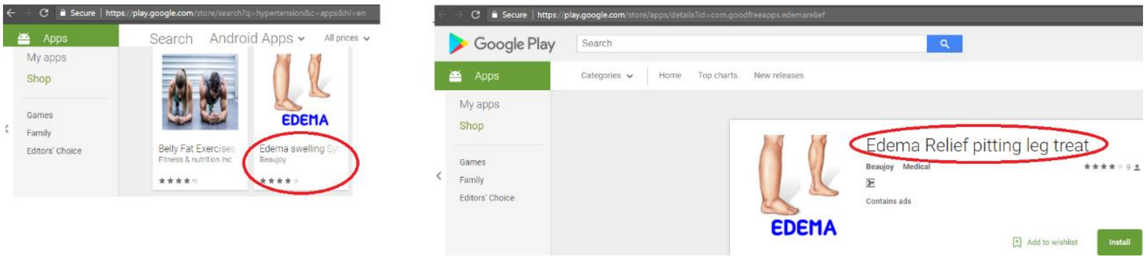


Figure 9: Differences in Android App Titles

Variations in names of apps between the two app stores required further screening for duplicates. An example was “Oxford Handbook of Nephrology and Hypertension, Second Edition” (iOS) compared with “Oxford Handbook Nephrolo&Hyp” (Android).

Ranking of search results in both the Android Google Play™ store and App Store® required considerable improvement so as to list the results in order of functionality for the consumer, since many apps were irrelevant and did not assist in self-management of hypertension. For example, the Android Google Play™ store listed "Blood Pressure Monitor" (by Timevy) on the fifth last row out of 28 rows in desktop web browser view, despite this app being clearly relevant to the search criteria, as opposed to recipes or exercises, which featured earlier in the ranked search results.

Furthermore, the results of the Android Google Play™ store search included the same app listed four times across two rows, as illustrated by Figure 10.

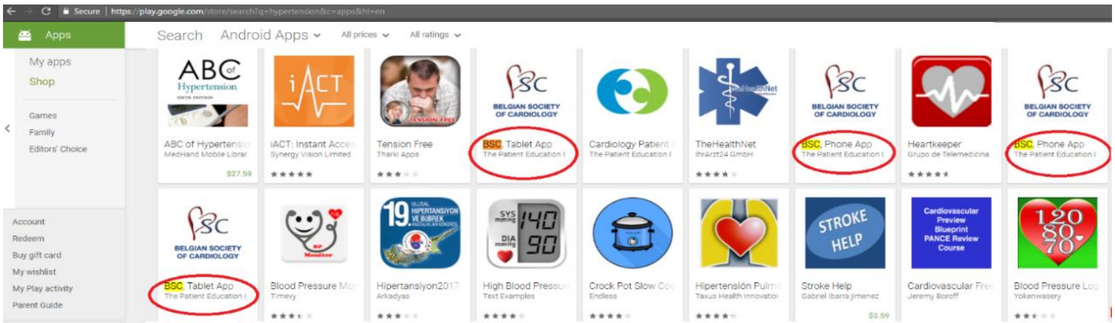


Figure 10: Duplicate Apps within same App Store

The randomised list of Apple and Android apps is presented in
Figure 11.

RANDOM.ORG

Do you own an iOS or Android device? Check out our app!

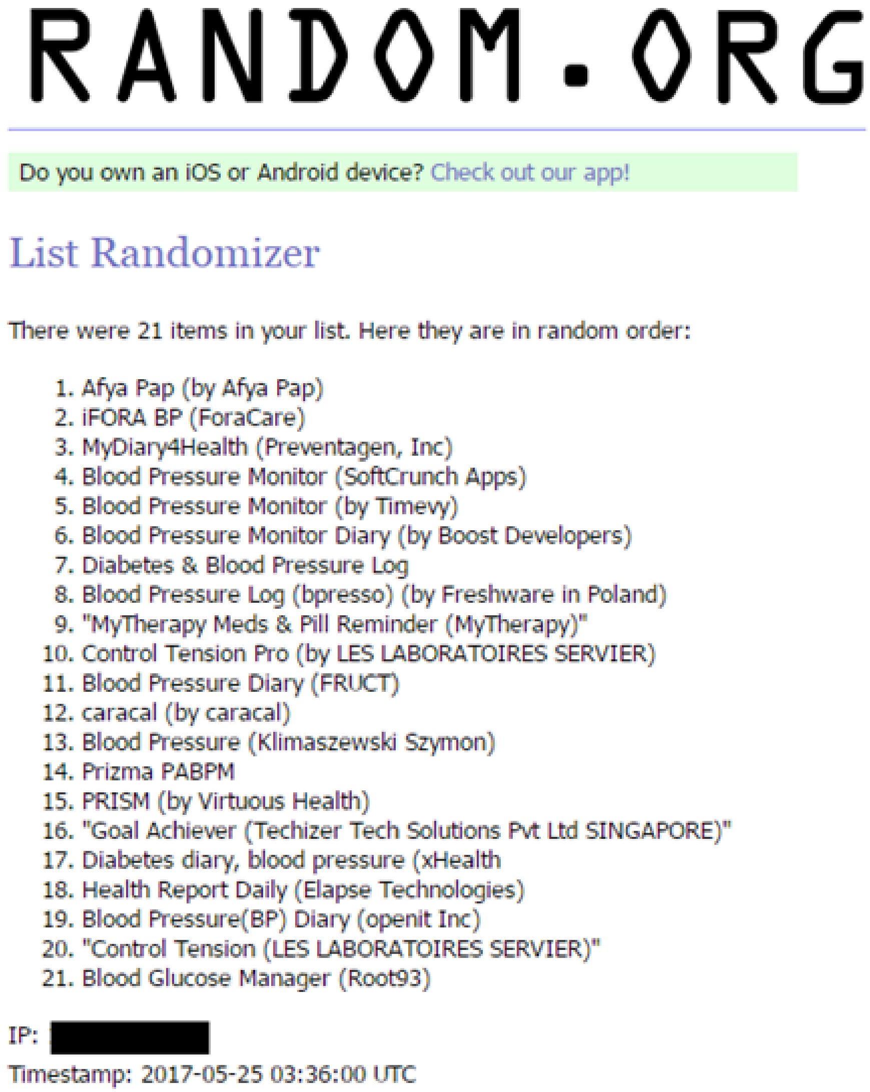
List Randomizer

There were 10 items in your list. Here they are in random order:

1. HoMedics
2. BP Tracker - Smart Blood Pressure Tracker (CN Guangdong)
3. Heart Sure
4. Pedia BP (no graphical features)
5. HeartStar Blood Pressure Monitor
6. Blood Pressure Companion Free
7. Monitor My BP for iPhone and iPad
8. Tactio Health: My Connected Health Logbook
9. Qardio Blood Pressure Monitor and Weight Tracker
10. Blood Pressure - Smart Blood Pressure (SmartBP) BP Tracker

IP: [redacted]

Timestamp: 2017-05-23 08:41:25 UTC



RANDOM.ORG

Do you own an iOS or Android device? Check out our app!

List Randomizer

There were 21 items in your list. Here they are in random order:

1. Afya Pap (by Afya Pap)
2. iFORA BP (ForaCare)
3. MyDiary4Health (Preventagen, Inc)
4. Blood Pressure Monitor (SoftCrunch Apps)
5. Blood Pressure Monitor (by Timevy)
6. Blood Pressure Monitor Diary (by Boost Developers)
7. Diabetes & Blood Pressure Log
8. Blood Pressure Log (bpresso) (by Freshware in Poland)
9. "MyTherapy Meds & Pill Reminder (MyTherapy)"
10. Control Tension Pro (by LES LABORATOIRES SERVIER)
11. Blood Pressure Diary (FRUCT)
12. caracal (by caracal)
13. Blood Pressure (Klimaszewski Szymon)
14. Prizma PABPM
15. PRISM (by Virtuous Health)
16. "Goal Achiever (Techizer Tech Solutions Pvt Ltd SINGAPORE)"
17. Diabetes diary, blood pressure (xHealth
18. Health Report Daily (Elapse Technologies)
19. Blood Pressure(BP) Diary (openit Inc)
20. "Control Tension (LES LABORATOIRES SERVIER)"
21. Blood Glucose Manager (Root93)

IP: [redacted]

Timestamp: 2017-05-25 03:36:00 UTC

Figure 11: Randomised Hypertension Management Apps (iOS and Android, respectively)

Download and initial familiarisation of the 31 shortlisted apps revealed the need for further elimination. The reasons are listed in Table 19. Examples warranting a specific mention were an app ("Afya Pap") that required verification from a UK or African mobile number to initialise the app, and another app ("Qardio") that would only proceed to the app upon pairing with a compatible device via Bluetooth®. These were exceptions unable to be anticipated in the shortlisting process. These additional exclusions reduced the 31 shortlisted apps to 17.

The key trends evident in Table 19 suggest the most common country of origin of the shortlisted hypertension monitoring apps was the US (n=8), followed by India (n=5) and France (n=3). Although all shortlisted apps had been updated within the previous 12 months (in accordance with the shortlisting protocol), over half (17 apps) were indicated as Version 2.0 or higher.

Table 19: Shortlisted Hypertension Clinical Management Apps as Randomised for Rating

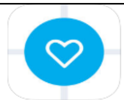
	App Icon	Country of Origin	Last Update Prior to Rating	Version	Key Functions other than Data Entry/Health Tracking	Reason for Exclusion*
Android						
Afya Pap™ (by Afya Pap)		London, UK	20.04.17	1.0.5	Unable to be assessed	Required UK or African mobile number to initiate app
iFORA BP™ (ForaCare)		California, United States of America (USA)	3.10.16	1.2.0	Unable to be assessed	No manual entry of readings – must be paired with device
MyDiary4Health™		San Diego, USA	05.03.17	1.0	Unable to be assessed	Google Access Issue on Samsung Galaxy S6 SM-G900F, OS 6.0.1
Blood Pressure Monitor (SoftCrunch Apps)		Kathmandu, Nepal	6.04.17	1.9	Unable to be assessed	Identified as a prank app upon initial trial; now re-named to "Finger Blood Pressure Prank" (verified 1 October 2017), hence the false positive in being shortlisted
Blood Pressure Monitor by Timevy		India	19.05.17	2.0	Graphical representation Provides hypertension fact sheet Historical analysis Permits offline data entry	Not applicable

Blood Pressure Monitor Diary by Boost Developers		Nepal (no city provided)	30.11.16	1.3.4	Graphical representation Provides hypertension fact sheet Permits offline data entry	Not applicable
Diabetes & Blood Pressure Log by Cooey Technologies		India	04.04.17	3.06	Graphical representation Provides goal setting Social media login (Facebook and Google) Reminders for medicine only (then crashes) Permits offline data entry Permits backdated entries	Not applicable
BPresso™ Blood Pressure Log		Lublin, Poland	19.04.2017	3.6	Graphical representation Privacy policy Reminders Social media Login (Facebook and Google) Third-party integration (mHealthBox) Permits backdated entries Notifications Permits offline data entry Edit pressure range (low, optimum, mild, moderate, severe hypertension)	Not applicable
MyTherapy Meds & Pill Reminder (MyTherapy)		UK	27.04.2017	3.21	Graphical representation Reminders Sharing of results with GP Voice entries permitted Privacy policy Notifications Social media Login (Facebook and Google)	Compatibility issues when downloading from Google Play™ store on certain devices

					Permits backdated entries Email yourself progress reports	
Control Tension **Pro**™ (by LES LABORATOIRES SERVIER)		Neuilly-sur-Seine, France	6.04.17	1.0.2	Unable to be assessed	Pro version unavailable in Google Play™ store during trial (regular version accessed)
Blood Pressure Diary (FRUCT)		St Petersburg, Russia	14.03.2017	3.1	Graphical representation Reminders Voice entries permitted Notifications (requires payment) Permits offline data entry	Not applicable
Caracal™ (by Caracal)		Paris, France	07.03.17	1.0.0	Unable to be assessed Can set systolic/diastolic pressure and heart rate goals	Compatibility issues with rater's Android devices, i.e.. Samsung Galaxy S6 SM-G900F, OS 6.0.1
My Heart / Blood Pressure by Klimaszewski Szymon		Wroclaw, Poland	14.05.17	3.12.05	Graphical representation Connection to peripheral device Requires user profile setup Allows multiple users Sharing of results with GP Reminders Export to CSV/XML Permits offline data entry	Not applicable
Prizma PABPM™		Belgrade, Serbia	31.03.17	1.0.34	Unable to be assessed	Opens, displays logo then kernel hangs with white screen
PRISM™ (by Virtuous Health)		Bangalore, India	9.05.17	1.0.4	Unable to be assessed	No manual data entry; synchronises with device only

Goal Achiever™ by Techizer Tech Solutions		Mumbai, India	13.05.17	7.0	Unable to be assessed	Doctor's code required to progress past first screen
(Laborum™) Diabetes diary, blod pressure Also known as Smart Health & Patient Support (Laborum) by xHealth		Hungary	02.05.16	2.1.7	Reminders Interactive drop-down medication list In-app Help Centre Permits backdated entries Permits offline data entry	Not applicable
Health Report Daily™ By Elapse Technologies		Quebec, Canada	16.10.2016	2.2.4	Graphical representation Permits offline data entry Email yourself progress reports	Not applicable
Blood Pressure (BP) Diary by OpenIt Inc		South Korea	02.04.2017	4.0.2	Unable to be assessed	Requests access to contacts list, then exits
Control Tension™ (Les Laboratoires Servier)		Neuilly-sur-Seine, France	06.04.2017	1.0.23	Graphical representation Permits backdated entries up to two days only Reminders Permits offline data entry Email yourself progress reports Reminders	Not applicable
Blood Glucose Manager by Root 93		Korea	29.05.2016	1.2.1	Text-based representation Permits backdated entries Permits offline data entry only when initially opened with Wi-Fi for that session	Not applicable
iOS						

HoMedics™		Michigan, US	03.12.2016	2.4.3.2	Connection to peripheral User profile MS HealthVault integration Permits offline data entry	Not applicable
BP Tracker – Smart Blood Pressure Tracker		Guangdong, China	19/04/2017	1.2.3	Unable to be assessed	Required pairing with a “customized Bluetooth electronic BP meter”
Heart Sure™		Melbourne, Australia	26.09.2016	1.7	Connection to peripheral User Profile Permits offline data entry	Not applicable
Pedia BP™		California, US	28/11/2016	3.2.0	Unable to be assessed	Designed for 2-17-year-olds as per the user profile setup; calculator-only function; doesn’t retrieve any saved data, even from same live session
HeartStar Blood Pressure Monitor		North Carolina, US	28.11.2016	3.2.0	Synchronisation with Apple Health Graphical representation Reminders User Profile Permits offline data entry	Not applicable
Blood Pressure Companion™ – BP Tracker and Log “BP Companion Free” By Maxwell Software		India	4.01.17	3.3.3	Graphical representation Reminders Export to CSV/HTML/PDF Permits offline data entry	Not applicable
Monitor My BP for iPhone and iPad		Maryland, US	18.12.16	2.1.2	Export to cloud Graphical representation Reminders	Not applicable

					User Profile Permits offline data entry	
Tactio Health™		Montreal, Canada	15.05.16	2.2	Graphical representation Reminders User Profile Export to cloud Permits offline data entry	Not applicable
Qardio™ Blood Pressure Monitor and Weight Tracker		California, US	20.10.16	5.2.1	Unable to be assessed	Works only with paired Bluetooth device
Blood Pressure - Smart Blood Pressure (SmartBP) BP Tracker		Plymouth, US	27.03.17	1.65.1	Export to cloud Graphical representation Integrated reminders – opens native iOS Reminders app User Profile MS HealthVault integration Permits offline data entry	Not applicable

* All apps were rated between 08 June 2017 and 13 July 2017

5.5.2 Results for Hypertension Apps via Consensus (between Three Raters)

The first app rated by consensus, “HoMedics”, demonstrated the highest total consensus score of 37.5/72.0 (Table 20). The highest-scoring construct of this app was Functionality, with a consensus score of 4.0/6.0. A user-friendly aesthetic was provided to consumers, along with colour-coded entries and the ability to set reminders was welcomed by the raters. A more intuitive graph feature to easily pin point individual readings would be welcomed.

“Heart Sure” was the other iOS app rated via consensus (Table 21). The highest-scoring construct of this app was Ease of Use, with a consensus score of 3.0/6.0 and overall score of 24.0/72.0. This app has since been removed from the iOS App Store®[189] but also included reminders, proving temperamental upon setup. Also, there was no privacy policy or any form of data assurance provided.

The highest-scoring construct for the Android app “Blood Pressure Monitor” by Timevy was Ease of Use, with a consensus score of 3.0/6.0; the Engagement construct scored 0.0/6.0 (Table 22), but scored the overall lowest total score out of any rated app, at 15.0/72.0. However, the hypertension information section relating to hypertensive ranges was welcomed by the raters.

The other Android app rated via consensus, “Blood Pressure Monitor” by Boost Developers, demonstrated the lowest possible Engagement and Functionality scores (Table 23). The highest-scoring constructs of this app were Ease of Use and Information Management, each with a score of 3.0/6.0, with an overall score of 18.0/72.0. Readings required manual typing, rather than scrolling; a simple and average user interface and graph feature was offered.

Table 20: Consensus Score for “HoMedics” V2.4.3.2, by HoMedics (iOS, rated June 2017)

Construct	Variable	ACDC Survey Questions	Consensus Score
Engagement	Gamification	Contains gaming principles (such as digital rewards, prizes, leaderboards, badges, aggregated readings or competitions)	0.0
	Customisation	Permits customisation of features (e.g. sound, content, notifications	0.0
	Interactivity	Allows free-text reflections alongside clinical data	1.0
	Engagement through use of plug-ins	Connects with a peripheral device	1.0
	Self-awareness	Encourages user to develop self-reflection and/or increased self-awareness	0.5
	Positive behaviour change	Encourages positive self-care practices e.g. using reminders, tips or social influences?	0.0
	Subtotal		**2.5/6.0**
Functionality	Health warnings	Produces warnings about, or highlights, out-of-range readings	0.5
	Feedback	Provides tactile, visual and/or sound feedback	0.5
	Structural navigation	Facilitates sequential/appropriate navigation	1.0
	Intuitive design	Presents intuitive use e.g. identifiable data input fields, intuitive symbols, generous touch areas	0.5
	Connection to health services	Sends or connects data to another service	1.0
	Performance power	Responds to app features (functions) and components (buttons/menus	0.5
	Subtotal		**4.0/6.0**
Ease of Use	Holistic usability	Captures self-management tasks easily in a single app	1.0
	Automation	Facilitates automation of tasks e.g. pre-populated fields, suggestions based on inputs, management of medical appointments, automated customer service	0.0
	Medical and technical jargon	Omits confusing (medical and/or technology) jargon	0.5
	User profile setup	Provides easy setup of user profile, e.g. option to login via social media account	0.5
	Offline mode	Operates core functionality in offline mode	1.0
	Reminders	Enables users to set reminders	0.5
	Subtotal		**3.5/6.0**

Information Management	Statistics	Permits analysis of clinical data e.g. produces statistics, graphs	0.5
	Privacy and data security	Allows secure data input and export e.g. password management, encryption, privacy statement, cloud backup	0.5
	Quality and accurate information	Accepts and displays correct, relevant information	1.0
	Quantity of information	Offers concise but still comprehensive information	0.0
	Visual information	Illustrates clear and logical charts, graphs, images, videos etc	0.0
	Credibility	Presents credible logo and cites research	0.5
	Subtotal		**2.5/6.0**
Total			**12.5/24.0**
Projected Total*			**37.5/72.0***

*Totals for apps rated by consensus measurement have been multiplied by three to produce the same denominator as individually-rated apps

Table 21: Consensus Score for "Heart Sure" V2.0.1 (iOS, rated June 2017)

Construct	Variable	ACDC Survey Questions	Consensus Score
Engagement	Gamification	Contains gaming principles (such as digital rewards, prizes, leaderboards, badges, aggregated readings or competitions)	0.0
	Customisation	Permits customisation of features (e.g. sound, content, notifications	0.0
	Interactivity	Allows free-text reflections alongside clinical data	0.0
	Engagement through use of plug-ins	Connects with a peripheral device	0.0
	Self-awareness	Encourages user to develop self-reflection and/or increased self-awareness	0.5
	Positive behaviour change	Encourages positive self-care practices e.g. using reminders, tips or social influences?	0.0
	Subtotal		**0.5/6.0**
Functionality	Health warnings	Produces warnings about, or highlights, out-of-range readings	0.0
	Feedback	Provides tactile, visual and/or sound feedback	0.0
	Structural navigation	Facilitates sequential/appropriate navigation	0.5
	Intuitive design	Presents intuitive use e.g. identifiable data input fields, intuitive symbols, generous touch areas	1.0
	Connection to health services	Sends or connects data to another service	0.0
	Performance power	Responds to app features (functions) and components (buttons/menus	1.0
	Subtotal		**2.5/6.0**
Ease of Use	Holistic usability	Captures self-management tasks easily in a single app	1.0
	Automation	Facilitates automation of tasks e.g. pre-populated fields, suggestions based on inputs, management of medical appointments, automated customer service	0.0
	Medical and technical jargon	Omits confusing (medical and/or technology) jargon	1.0
	User profile setup	Provides easy setup of user profile, e.g. option to login via social media account	0.5
	Offline mode	Operates core functionality in offline mode	0.0
	Reminders	Enables users to set reminders	0.5
	Subtotal		**3.0/6.0**

Information Management	Statistics	Permits analysis of clinical data e.g. produces statistics, graphs	0.0
	Privacy and data security	Allows secure data input and export e.g. password management, encryption, privacy statement, cloud backup	0.0
	Quality and accurate information	Accepts and displays correct, relevant information	0.5
	Quantity of information	Offers concise but still comprehensive information	1.0
	Visual information	Illustrates clear and logical charts, graphs, images, videos etc	0.5
	Credibility	Presents credible logo and cites research	0.0
	Subtotal		**2.0/6.0**
Total			**8.0/24.0**
Projected Total*			**24.0/72.0***

*Totals for apps rated by consensus measurement have been multiplied by three to produce the same denominator as individually-rated apps

Table 22: Consensus Score for "Blood Pressure Monitor" V1.3.4, by Timevy (Android, rated June 2017)

Construct	Variable	ACDC Survey Questions	Consensus Score
Engagement	Gamification	Contains gaming principles (such as digital rewards, prizes, leaderboards, badges, aggregated readings or competitions)	0.0
	Customisation	Permits customisation of features (e.g. sound, content, notifications	0.0
	Interactivity	Allows free-text reflections alongside clinical data	0.0
	Engagement through use of plug-ins	Connects with a peripheral device	0.0
	Self-awareness	Encourages user to develop self-reflection and/or increased self-awareness	0.0
	Positive behaviour change	Encourages positive self-care practices e.g. using reminders, tips or social influences?	0.0
	Subtotal		**0.0/6.0**
Functionality	Health warnings	Produces warnings about, or highlights, out-of-range readings	0.0
	Feedback	Provides tactile, visual and/or sound feedback	0.0
	Structural navigation	Facilitates sequential/appropriate navigation	0.0
	Intuitive design	Presents intuitive use e.g. identifiable data input fields, intuitive symbols, generous touch areas	0.0
	Connection to health services	Sends or connects data to another service	0.0
	Performance power	Responds to app features (functions) and components (buttons/menus	1.0
	Subtotal		**1.0/6.0**
Ease of Use	Holistic usability	Captures self-management tasks easily in a single app	1.0
	Automation	Facilitates automation of tasks e.g. pre-populated fields, suggestions based on inputs, management of medical appointments, automated customer service	0.0
	Medical and technical jargon	Omits confusing (medical and/or technology) jargon	1.0
	User profile setup	Provides easy setup of user profile, e.g. option to login via social media account	0.0
	Offline mode	Operates core functionality in offline mode	1.0
	Reminders	Enables users to set reminders	0.0
	Subtotal		**3.0/6.0**

Information Management	Statistics	Permits analysis of clinical data e.g. produces statistics, graphs	0.0
	Privacy and data security	Allows secure data input and export e.g. password management, encryption, privacy statement, cloud backup	0.0
	Quality and accurate information	Accepts and displays correct, relevant information	0.5
	Quantity of information	Offers concise but still comprehensive information	0.5
	Visual information	Illustrates clear and logical charts, graphs, images, videos etc	0.0
	Credibility	Presents credible logo and cites research	0.0
	Subtotal		**1.0/6.0**
Total			**5.0/24.0**
Projected Total*			**15.0/72.0**

*Totals for apps rated by consensus measurement have been multiplied by three to produce the same denominator as individually-rated apps.

Table 23: Consensus Score for “Blood Pressure Monitor” v2.0, by Boost Developers (Android, rated June 2017)

Construct	Variable	ACDC Survey Questions	Consensus Score
Engagement	Gamification	Contains gaming principles (such as digital rewards, prizes, leaderboards, badges, aggregated readings or competitions)	0.0
	Customisation	Permits customisation of features (e.g. sound, content, notifications	0.0
	Interactivity	Allows free-text reflections alongside clinical data	0.0
	Engagement through use of plug-ins	Connects with a peripheral device	0.0
	Self-awareness	Encourages user to develop self-reflection and/or increased self-awareness	0.0
	Positive behaviour change	Encourages positive self-care practices e.g. using reminders, tips or social influences?	0.0
	Subtotal		**0.0/6.0**
Functionality	Health warnings	Produces warnings about, or highlights, out-of-range readings	0.0
	Feedback	Provides tactile, visual and/or sound feedback	0.0
	Structural navigation	Facilitates sequential/appropriate navigation	0.0
	Intuitive design	Presents intuitive use e.g. identifiable data input fields, intuitive symbols, generous touch areas	0.0
	Connection to health services	Sends or connects data to another service	0.0
	Performance power	Responds to app features (functions) and components (buttons/menus	0.0
	Subtotal		**0.0/6.0**
Ease of Use	Holistic usability	Captures self-management tasks easily in a single app	1.0
	Automation	Facilitates automation of tasks e.g. pre-populated fields, suggestions based on inputs, management of medical appointments, automated customer service	0.0
	Medical and technical jargon	Omits confusing (medical and/or technology) jargon	1.0
	User profile setup	Provides easy setup of user profile, e.g. option to login via social media account	0.0
	Offline mode	Operates core functionality in offline mode	1.0
	Reminders	Enables users to set reminders	0.0
	Subtotal		**3.0/6.0**

Information Management	Statistics	Permits analysis of clinical data e.g. produces statistics, graphs	0.5
	Privacy and data security	Allows secure data input and export e.g. password management, encryption, privacy statement, cloud backup	0.0
	Quality and accurate information	Accepts and displays correct, relevant information	0.5
	Quantity of information	Offers concise but still comprehensive information	1.0
	Visual information	Illustrates clear and logical charts, graphs, images, videos etc	0.0
	Credibility	Presents credible logo and cites research	1.0
	Subtotal		**3.0/6.0**
Total			**6.0/24.0**
Projected Total*			**18.0/72.0**

*Totals for apps rated by consensus measurement have been multiplied by three to produce the same denominator as individually-rated apps

5.5.3 Results for Hypertension Apps rated Independently

Table 24 to Table 36 present the individually-rated Android apps.

“HeartStar Blood Pressure Monitor”, the first app to be assessed independently by three raters, presented Functionality as its highest-scoring construct at 15.0/18.0. This app also held the most consistent Functionality construct ICC possible, with an ICC score of 1.0 (Table 24). The highest scoring construct for this app was also Functionality, whilst the lowest-scoring construct of this app was Engagement, with a score of 7.0/18.0. Moderation was not required for any domain. Additionally, no health information, such as measurement technique or ways to reduce high blood pressure, was provided. The reminder function was not permitted but the app did include a points system to gamify one’s monitoring. Also, no height or weight was required, which was not well received by the raters.

“Blood Pressure Companion Free” (Table 25) featured adequate offline mode access, but users could not backdate entries, in contrast to all other rated apps and presented Ease of Use as its highest-scoring construct at 14.0/18.0. A DropBox® backup feature was present, not observed for any other shortlisted app. The continuous in-app marketing content could be improved to facilitate a less-invasive user experience. The choice of imperial or metrics units was useful, along with the passcode option, the colour-coded summary in data entry and graph view, and functionality to enter daily weight; however, the graphs were restricted to weekly views. Additionally, performance was limited by pop-ups and advertising that the user was required to manually close in order to resume using the app.

“Monitor my BP for iPhone and iPad” exhibited the second-lowest overall score out of all assessed iOS apps (Table 26). Despite this low score, all constructs exhibited high ICC values of 0.85-0.97. The highest-scoring construct of this app was Ease of Use, with a score of 11.5/18.0. This app provided the user with good instructions but featured no user profile with annoying and distracting banner advertising. The “taken at” feature did not clearly refer to a time or location which the reading was taken at and the input field did not suggest either option. Smaller buttons such as ‘Add’, ‘Menu’ and the scroll bar made it slightly more difficult to navigate. Additionally, no interpretation of data was presented, only basic tabulation available.

"Tactio Health" provided users with an End User License Agreement and password option (Table 27), and attained the highest score of all shortlisted apps (56.5/72.0), with Information Management as its highest-scoring construct at 16.5/18.0. However, this app was associated with the lowest consistency between raters, with the Engagement construct generating an ICC of 0.22. Since less than 10% of ICC values were <0.7, no moderation was undertaken, as described in Sections 5.6.2 and 5.6.4. Unique features not available in other apps included adding a coach, profile photo and waist measurements. Limited touch areas were noted along with bad choice of colours for essential buttons such as 'Save'. Heavy focus on weight and diet was noted. Customisation focussed on input of measurements, rather than colour schemes. This app presented a more holistic health management solution than other rated apps, displayed intuitive colour codes, and categorised readings such as 'high normal pulse' intuitively. Other positive features included a comprehensive PDF of entered clinical data, colour report PDF (with custom weeks), and notes function for text, photo and audio input.

"SmartBP" presented the second-highest score of all shortlisted apps. This app featured a connection to Microsoft HealthVault (Table 28), with Ease of Use as the highest-scoring construct at 13.5/18.0. Adequate offline mode capability and security features, such as login credentials and privacy policy, were also noted. Its highest-scored ICC was Information Management, at 0.95. Some profile fields were not responsive, and saving each record was an issue. This app could synchronise via BlueTooth® with a blood pressure monitor, auto-calculate BMI, permit daily weight readings, save to the cloud, and permit PDF export via email, but it contained advertising. Significant flaws presented in the graph feature, and the axis appeared stuck. Customising own ranges and cut-offs was useful. No central dashboard resulted in difficult navigation; however, a Tweet/share option was available.

"Diabetes and Blood Pressure Log" V3.06, by Cooey Technologies, was the first Android app to be rated, with a total score of 37.5/72.0, and its highest-scoring construct Ease of Use construct at 12.5/18.0. The Information Management construct presented the lowest of all Android Information Management ICC values at 0.66; 0.87, the highest was aligned with the Engagement construct. Usability-wise, raters found it difficult reading the calendar layout and navigation was unstructured.

The voice command feature was welcomed, but did not consistently capture correct user prompts. Additionally, the graph mode did not display gaps in readings to reflect the missing blood pressure readings in the dummy profile.

“Blood Pressure Log (bPresso)” attained the highest Android app rating, with a total of 43.0/72.0, with Ease of Use presenting the highest-scoring construct at 13.5/18.0. Ease of Use presented the highest ICC at 0.87; the lowest ICC was Information Management, at 0.79. This app was easy to use, contained aesthetically-pleasing green, orange and red hearts to match readings, and permitted notetaking against readings, but limited medication details were provided. Filtering the log view based on weight, activity and lab tests was welcomed, and the reminder feature worked.

“Blood Pressure Diary” scored a total of 34.5/72.0, with Ease of Use presenting the highest-scoring construct at 12.0/18.0. Information Management was again the lowest ICC value at 0.75. The cached values provided users efficiency by avoiding re-typing readings for subsequent periods/days. Although the green, orange, red colour-coded bars were welcomed in data entry mode, this was not evident in graph mode. A custom date range could not be selected; instead, a weekly, monthly, quarterly or yearly option was presented. Medication package and reminders only presented in the paid Pro version. Creation of a user profile would have been welcomed by the raters.

“Blood Pressure” by Klimaszewski Szymon scored a total of 40.0/72.0, with Ease of Use presenting the highest-scoring construct at 13.5/18.0. The Engagement and Functionality constructs presented equal lowest ICC values at 0.78, with Information Management presenting the highest construct for that app at 0.86. The home screen presented poor English, but detailed, simple instructions were provided throughout the app, including automatic synchronisation to one’s Google account. Comparatively, “Blood Pressure” provided more instructions than other rated apps, and larger fields were provided to scroll or type numbered readings. Illogical colour coding contrary to conventions were provided, e.g. red for all systolic readings and green for all diastolic readings in both data entry and graph view since the app did not differentiate between high/low readings which are reserved for red and green colours. The reminder feature worked. Similar to “Blood Pressure Diary”, the previous cached values provided users efficiency by avoiding re-typing readings.

“Diabetes Diary, Glucose, Insulin Monitor (Laborom)” presented a total score of 38.5/72.0, with the Engagement construct presenting the highest ICC value for the app at 0.88. Again, Information Management presented the lowest ICC value at 0.80. Entering readings after completing the user profile would have been welcomed by the raters. The reminder feature was only for administering medication, rather than taking blood pressure readings. The email report feature was useful. Limited analysis was available, and no colour coding was present in graph mode.

“Health Report Daily” scored the lowest total score out of all individual-rated apps with 16.5/72.0; however inter-rater agreement was strong across all constructs with the lowest and highest values at 0.82 and 0.94, respectively, for Information Management and Ease of Use. This app was one of the most awkward and unappealing to use, and also contained intrusive advertising, with Ease of Use presenting the highest-scoring construct at 8.0/18.0. An option to change pounds to kilos was welcomed. Data scrolling was unconventional, and this app took considerably longer than other rated apps to navigate. No ‘save’ feature for readings was noted. No instructions for systolic or diastolic were provided, and systolic readings erroneously presented as diastolic readings in graph mode. Gaps in readings as per the dummy profile were also inaccurately logged as ‘0’. Filtering was limited to calendar months such as June or July. The email feature worked; however, no instructions were provided, no user profile existed to establish demographic data or a password, readings were not colour coded, and loading of graphs lagged considerably, possibly due to advertising.

“Control Tension” achieved a total score of 26.0/72.0, with Ease of Use and Information Management equally presenting the highest-scoring construct at 9.5/18.0. The lowest ICC value being Engagement for this app at 0.57 and the highest ICC value Ease of Use at 0.95. Similar to the Engagement construct for “Tactio Health”, less than 10% of ICC values were <0.7, so no moderation was undertaken, as described in Sections 5.6.2 and 5.6.4. The Privacy Statement was welcomed, and rarely seen in the selected apps. However, the home menu provided small touch areas, and a slight lag was noted. Graph mode could only be customised to one seven-day weekly date range, losing archived data from week to week, no colour-coded zones were provided in graph mode, and no statistics (such as the average reading) were provided. Lifestyle advice was welcomed, but did not link to high readings to alert the user. The ‘email as a PDF or CSV’ feature was useful. References did not link to particular information in the app, and limited evidence suggested these references were used to strengthen credibility.

“Blood Glucose Manager” by Root93 scored a total of 23.5/72.0, with Ease of Use presenting the highest-scoring construct at 7.5/18.0. Information Management presented the lowest ICC value at 0.79; the remaining ICC values ranged from the low to high 0.90’s. The app presented a confusing name, since it allowed blood pressure (as well as glucose and HbA1c) readings, but pulse readings were not supported. The app defaulted to glucose readings after each blood pressure reading, requiring extra time to switch back. A deliberate error attempted by the raters uncovered a flaw enabling diastolic readings to be higher than systolic, which is not clinically possible. Log view only displayed readings as green or red, with no amber. Advertising was noted. No user profile was available, and severe errors in graphs view were noted, for example, minimum/maximum readings did not correspond to the entered readings.

Table 24: Scores for "HeartStar Blood Pressure Monitor" V 7.7.5, by Pattern Health (iOS, rated June 2017)

Construct	Variable	ACDC Survey Questions	Rater 1	Rater 2	Rater 3	Original -> Adjusted ICC	Original -> Adjusted Total
Engagement	Gamification	Contains gaming principles (such as digital rewards, prizes, leaderboards, badges, aggregated readings or competitions)	0.5	0.5	0.5		
	Customisation	Permits customisation of features (e.g. sound, content, notifications	0.0	0.0	0.0		
	Interactivity	Allows free-text reflections alongside clinical data	1.0	1.0	1.0		
	Engagement through use of plug-ins	Connects with a peripheral device	0.0	0.0	0.0		
	Self-awareness	Encourages user to develop self-reflection and/or increased self-awareness	0.0	1.0	0.5		
	Positive behaviour change	Encourages positive self-care practices e.g. using reminders, tips or social influences?	0.5	0.0	0.5		
	Subtotal		**2.0**	**2.5**	**2.5**	**0.85**	**7.0**
Functionality	Health warnings	Produces warnings about, or highlights, out-of-range readings	1.0	1.0	1.0		
	Feedback	Provides tactile, visual and/or sound feedback	0.0	0.0	0.0		
	Structural navigation	Facilitates sequential/appropriate navigation	1.0	1.0	1.0		

	Intuitive design	Presents intuitive use e.g. identifiable data input fields, intuitive symbols, generous touch areas	1.0	1.0	1.0		
	Connection to health services	Sends or connects data to another service	1.0	1.0	1.0		
	Performance power	Responds to app features (functions) and components (buttons/menus)	1.0	1.0	1.0		
	Subtotal		**5.0**	**5.0**	**5.0**	**1.0**	**15.0**
Ease of Use	Holistic usability	Captures self-management tasks easily in a single app	1.0	1.0	1.0		
	Automation	Facilitates automation of tasks e.g. pre-populated fields, suggestions based on inputs, management of medical appointments, automated customer service	0.0	0.0	0.0		
	Medical and technical jargon	Omits confusing (medical and/or technology) jargon	1.0	1.0	1.0		
	User profile setup	Provides easy setup of user profile, e.g. option to login via social media account	0.5	0.5	0.5		
	Offline mode	Operates core functionality in offline mode	1.0	1.0	1.0		
	Reminders	Enables users to set reminders	0.5	0.0	0.5		
	Subtotal		**4.0**	**3.5**	**4.0**	**0.98**	**11.5**
Information Management	Statistics	Permits analysis of clinical data e.g. produces statistics, graphs	1.0	1.0	1.0		
	Privacy and data security	Allows secure data input and export e.g. password management, encryption, privacy statement, cloud backup	0.5	0.0	0.5		
	Quality and accurate information	Accepts and displays correct, relevant information	1.0	1.0	0.5		

	Quantity of information	Offers concise but still comprehensive information	0.5	0.0	0.5		
	Visual information	Illustrates clear and logical charts, graphs, images, videos etc	1.0	1.0	1.0		
	Credibility	Presents credible logo and cites research	0.5	0.0	0.5		
	Subtotal		**4.0**	**3.0**	**4.0**	**0.86**	**11.0**
Total			**15.0**	**14.0**	**15.5**		**44.5/72.0**

Table 25: Scores for “Blood Pressure Companion Free” V 3.3.3, by Maxwell Software (iOS, rated June 2017)

Construct	Variable	ACDC Survey Questions	Rater 1	Rater 2	Rater 3	Original -> Adjusted ICC	Original -> Adjusted Total
Engagement	Gamification	Contains gaming principles (such as digital rewards, prizes, leaderboards, badges, aggregated readings or competitions)	0.5	0.0	0.5		
	Customisation	Permits customisation of features (e.g. sound, content, notifications	0.0	0.0	0.0		
	Interactivity	Allows free-text reflections alongside clinical data	1.0	1.0	1.0		
	Engagement through use of plug-ins	Connects with a peripheral device	0.0	0.0	0.0		
	Self-awareness	Encourages user to develop self-reflection and/or increased self-awareness	1.0	0.5	1.0		

	Positive behaviour change	Encourages positive self-care practices e.g. using reminders, tips or social influences?	0.0	0.0	0.0		
	Subtotal		**2.5**	**1.5**	**2.5**	**0.96**	**6.5**
Functionality	Health warnings	Produces warnings about, or highlights, out-of-range readings	0.5	0.5	0.5		
	Feedback	Provides tactile, visual and/or sound feedback	0.5	0.0	0.5		
	Structural navigation	Facilitates sequential/appropriate navigation	1.0	1.0	1.0		
	Intuitive design	Presents intuitive use e.g. identifiable data input fields, intuitive symbols, generous touch areas	1.0	1.0	1.0		
	Connection to health services	Sends or connects data to another service	0.5	0.0	0.5		
	Performance power	Responds to app features (functions) and components (buttons/menus)	1.0	0.5	1.0		
	Subtotal		**4.5**	**3.0**	**4.5**	**0.92**	**12.0**
Ease of Use	Holistic usability	Captures self-management tasks easily in a single app	1.0	1.0	1.0		
	Automation	Facilitates automation of tasks e.g. pre-populated fields, suggestions based on inputs, management of medical appointments, automated customer service	0.5	0.0	0.5		
	Medical and technical jargon	Omits confusing (medical and/or technology) jargon	1.0	1.0	1.0		
	User profile setup	Provides easy setup of user profile, e.g. option to login via social media account	1.0	0.5	1.0		
	Offline mode	Operates core functionality in offline mode	1.0	1.0	1.0		

	Reminders	Enables users to set reminders	0.5	0.5	0.5		
	Subtotal		**5.0**	**4.0**	**5.0**	**0.91**	**14.0**
Information Management	Statistics	Permits analysis of clinical data e.g. produces statistics, graphs	1.0	1.0	1.0		
	Privacy and data security	Allows secure data input and export e.g. password management, encryption, privacy statement, cloud backup	1.0	1.0	1.0		
	Quality and accurate information	Accepts and displays correct, relevant information	1.0	1.0	1.0		
	Quantity of information	Offers concise but still comprehensive information	0.0	0.0	0.0		
	Visual information	Illustrates clear and logical charts, graphs, images, videos etc	1.0	1.0	1.0		
	Credibility	Presents credible logo and cites research	0.0	0.0	0.0		
	Subtotal		**4.0**	**4.0**	**4.0**	**1.0**	**12.0**
Total			**16.0**	**12.5**	**16.0**		**44.5/72.0**

Table 26: Scores for “Monitor My BP for iPhone and iPad” V 2.1.2, by APG Solutions, LLC (iOS, rated June 2017)

Construct	**Variable**	**ACDC Survey Questions**	**Rater 1**	**Rater 2**	**Rater 3**	**Original -> Adjusted ICC**	**Original -> Adjusted Total**
Engagement	Gamification	Contains gaming principles (such as digital rewards, prizes, leaderboards, badges, aggregated readings or competitions)	0.0	0.0	0.0		

	Customisation	Permits customisation of features (e.g. sound, content, notifications	0.5	0.0	0.5		
	Interactivity	Allows free-text reflections alongside clinical data	1.0	1.0	1.0		
	Engagement through use of plug-ins	Connects with a peripheral device	0.0	0.0	0.0		
	Self-awareness	Encourages user to develop self-reflection and/or increased self-awareness	0.0	0.0	0.0		
	Positive behaviour change	Encourages positive self-care practices e.g. using reminders, tips or social influences?	0.0	0.0	0.0		
	Subtotal		**1.5**	**1.0**	**1.5**	**0.97**	**4.0**
Functionality	Health warnings	Produces warnings about, or highlights, out-of-range readings	0.0	0.0	0.0		
	Feedback	Provides tactile, visual and/or sound feedback	0.5	0.0	0.5		
	Structural navigation	Facilitates sequential/appropriate navigation	0.0	0.0	0.0		
	Intuitive design	Presents intuitive use e.g. identifiable data input fields, intuitive symbols, generous touch areas	0.5	0.0	0.5		
	Connection to health services	Sends or connects data to another service	0.5	0.5	0.5		
	Performance power	Responds to app features (functions) and components (buttons/menus)	1.0	1.0	1.0		
	Subtotal		**2.5**	**1.5**	**2.5**	**0.95**	**6.5**
Ease of Use	Holistic usability	Captures self-management tasks easily in a single app	1.0	1.0	1.0		
	Automation	Facilitates automation of tasks e.g. pre-populated fields, suggestions based on inputs, management of medical	0.5	0.0	0.5		

		appointments, automated customer service					
	Medical and technical jargon	Omits confusing (medical and/or technology) jargon	1.0	1.0	1.0		
	User profile setup	Provides easy setup of user profile, e.g. option to login via social media account	0.0	0.0	0.0		
	Offline mode	Operates core functionality in offline mode	1.0	1.0	1.0		
	Reminders	Enables users to set reminders	0.5	0.5	0.5		
	Subtotal		**4.0**	**3.5**	**4.0**	**0.97**	**11.5**
Information Management	Statistics	Permits analysis of clinical data e.g. produces statistics, graphs	0.5	0.0	0.5		
	Privacy and data security	Allows secure data input and export e.g. password management, encryption, privacy statement, cloud backup	0.0	0.0	0.0		
	Quality and accurate information	Accepts and displays correct, relevant information	0.5	0.5	0.5		
	Quantity of information	Offers concise but still comprehensive information	0.0	0.0	0.0		
	Visual information	Illustrates clear and logical charts, graphs, images, videos etc	0.5	0.0	0.5		
	Credibility	Presents credible logo and cites research	0.0	0.0	0.0		
	Subtotal		**1.5**	**0.5**	**1.5**	**0.85**	**3.5**
Total			**9.5**	**6.5**	**9.5**		**25.5/72.0**

Table 27: Scores for "Tactio Health" V2.2, by Tactio Health Group Inc (iOS, rated June 2017)

Construct	Variable	ACDC Survey Questions	Rater 1	Rater 2	Rater 3	Original -> Adjusted ICC	Original -> Adjusted Total
Engagement	Gamification	Contains gaming principles (such as digital rewards, prizes, leaderboards, badges, aggregated readings or competitions)	0.5	0.0	0.5		
	Customisation	Permits customisation of features (e.g. sound, content, notifications	1.0	0.0	1.0		
	Interactivity	Allows free-text reflections alongside clinical data	1.0	1.0	1.0		
	Engagement through use of plug-ins	Connects with a peripheral device	0.5	0.5	1.0		
	Self-awareness	Encourages user to develop self-reflection and/or increased self-awareness	1.0	1.0	1.0		
	Positive behaviour change	Encourages positive self-care practices e.g. using reminders, tips or social influences?	1.0	1.0	0.0		
	Subtotal		**5.0**	**3.5**	**4.5**	**0.22**	**13.0**
Functionality	Health warnings	Produces warnings about, or highlights, out-of-range readings	1.0	1.0	1.0		
	Feedback	Provides tactile, visual and/or sound feedback	0.5	0.0	0.5		
	Structural navigation	Facilitates sequential/appropriate navigation	1.0	1.0	1.0		

	Intuitive design	Presents intuitive use e.g. identifiable data input fields, intuitive symbols, generous touch areas	1.0	0.5	1.0		
	Connection to health services	Sends or connects data to another service	0.5	0.5	1.0		
	Performance power	Responds to app features (functions) and components (buttons/menus)	1.0	1.0	1.0		
	Subtotal		**5.0**	**4.0**	**5.5**	**0.85**	**14.5**
Ease of Use	Holistic usability	Captures self-management tasks easily in a single app	1.0	1.0	1.0		
	Automation	Facilitates automation of tasks e.g. pre-populated fields, suggestions based on inputs, management of medical appointments, automated customer service	0.5	0.0	0.5		
	Medical and technical jargon	Omits confusing (medical and/or technology) jargon	1.0	1.0	1.0		
	User profile setup	Provides easy setup of user profile, e.g. option to login via social media account	1.0	1.0	0.5		
	Offline mode	Operates core functionality in offline mode	1.0	1.0	1.0		
	Reminders	Enables users to set reminders	0.0	0.0	0.0		
	Subtotal		**4.5**	**4.0**	**4.0**	**0.94**	**12.5**
Information Management	Statistics	Permits analysis of clinical data e.g. produces statistics, graphs	1.0	1.0	1.0		
	Privacy and data security	Allows secure data input and export e.g. password management, encryption, privacy statement, cloud backup	1.0	1.0	1.0		
	Quality and accurate information	Accepts and displays correct, relevant information	1.0	1.0	1.0		

	Quantity of information	Offers concise but still comprehensive information	1.0	0.5	1.0		
	Visual information	Illustrates clear and logical charts, graphs, images, videos etc	1.0	1.0	1.0		
	Credibility	Presents credible logo and cites research	1.0	0.0	1.0		
	Subtotal		**6.0**	**4.5**	**6.0**	**0.0**	**16.5**
Total			**20.5**	**16.0**	**20.0**		**56.5/72.0**

Table 28: Scores for "Blood Pressure - Smart Blood Pressure (SmartBP) BP Tracker" V 1.65.1 by Evolve Medical Systems, LLC (iOS, rated June 2017)

Construct	**Variable**	**ACDC Survey Questions**	**Rater 1**	**Rater 2**	**Rater 3**	**Original -> Adjusted ICC**	**Original -> Adjusted Total**
Engagement	Gamification	Contains gaming principles (such as digital rewards, prizes, leaderboards, badges, aggregated readings or competitions)	0.5	0.0	0.5		
	Customisation	Permits customisation of features (e.g. sound, content, notifications	0.5	0.5	0.5		
	Interactivity	Allows free-text reflections alongside clinical data	1.0	1.0	1.0		
	Engagement through use of plug-ins	Connects with a peripheral device	1.0	1.0	1.0		
	Self-awareness	Encourages user to develop self-reflection and/or increased self-awareness	1.0	0.5	1.0		

	Positive behaviour change	Encourages positive self-care practices e.g. using reminders, tips or social influences?	0.5	0.0	0.5		
	Subtotal		**4.5**	**3.0**	**4.5**	**0.91**	**12.0**
Functionality	Health warnings	Produces warnings about, or highlights, out-of-range readings	0.5	0.5	0.5		
	Feedback	Provides tactile, visual and/or sound feedback	0.5	0.0	0.5		
	Structural navigation	Facilitates sequential/appropriate navigation	1.0	0.0	1.0		
	Intuitive design	Presents intuitive use e.g. identifiable data input fields, intuitive symbols, generous touch areas	1.0	0.0	1.0		
	Connection to health services	Sends or connects data to another service	1.0	1.0	1.0		
	Performance power	Responds to app features (functions) and components (buttons/menus)	1.0	0.5	1.0		
	Subtotal		**5.0**	**2.0**	**5.0**	**0.60**	**12.0**
Ease of Use	Holistic usability	Captures self-management tasks easily in a single app	1.0	1.0	1.0		
	Automation	Facilitates automation of tasks e.g. pre-populated fields, suggestions based on inputs, management of medical appointments, automated customer service	0.5	0.0	0.5		
	Medical and technical jargon	Omits confusing (medical and/or technology) jargon	1.0	0.5	1.0		
	User profile setup	Provides easy setup of user profile, e.g. option to login via social media account	0.5	0.5	0.5		
	Offline mode	Operates core functionality in offline mode	1.0	1.0	1.0		

	Reminders	Enables users to set reminders	1.0	0.5	1.0		
	Subtotal		**5.0**	**3.5**	**5.0**	**0.88**	**13.5**
Information Management	Statistics	Permits analysis of clinical data e.g. produces statistics, graphs	1.0	0.5	1.0		
	Privacy and data security	Allows secure data input and export e.g. password management, encryption, privacy statement, cloud backup	1.0	1.0	1.0		
	Quality and accurate information	Accepts and displays correct, relevant information	1.0	1.0	1.0		
	Quantity of information	Offers concise but still comprehensive information	0.0	0.0	0.0		
	Visual information	Illustrates clear and logical charts, graphs, images, videos etc	0.5	0.5	0.5		
	Credibility	Presents credible logo and cites research	0.5	0.0	0.5		
	Subtotal		**4.0**	**3.0**	**4.0**	**0.95**	**11.0**
Total			**18.5**	**11.5**	**18.5**		**48.5/72.0**

Table 29: Scores for “Diabetes and Blood Pressure Log” V3.06, by Cooey Technologies (Android, rated July 2017)

Construct	Variable	ACDC Survey Questions	Rater 1	Rater 2	Rater 3	Original -> Adjusted ICC	Original -> Adjusted Total
Engagement	Gamification	Contains gaming principles (such as digital rewards, prizes, leaderboards, badges, aggregated readings or competitions)	0.5	0.5	0.5		
	Customisation	Permits customisation of features (e.g. sound, content, notifications	0.5	0.5	0.5		
	Interactivity	Allows free-text reflections alongside clinical data	1.0	1.0	1.0		
	Engagement through use of plug-ins	Connects with a peripheral device	1.0	0.0	1.0		
	Self-awareness	Encourages user to develop self-reflection and/or increased self-awareness	0.5	0.5	0.5		
	Positive behaviour change	Encourages positive self-care practices e.g. using reminders, tips or social influences?	0.5	0.5	0.5		
	Subtotal		**3.0**	**1.0**	**2.5**	**0.87**	**6.5**
Functionality	Health warnings	Produces warnings about, or highlights, out-of-range readings	0.5	0.5	0.5		
	Feedback	Provides tactile, visual and/or sound feedback	0.5	0.0	0.0		
	Structural navigation	Facilitates sequential/appropriate navigation	0.5	0.5	0.5		
	Intuitive design	Presents intuitive use e.g. identifiable data input fields, intuitive symbols, generous touch areas	1.0	1.0	1.0		
	Connection to health services	Sends or connects data to another service	0.5	0.5	0.5		

	Performance power	Responds to app features (functions) and components (buttons/menus)	0.5	1.0	0.5		
	Subtotal		**3.5**	**3.5**	**3.0**	**0.86**	**10.0**
Ease of Use	Holistic usability	Captures self-management tasks easily in a single app	1.0	1.0	1.0		
	Automation	Facilitates automation of tasks e.g. pre-populated fields, suggestions based on inputs, management of medical appointments, automated customer service	0.5	0.0	0.0		
	Medical and technical jargon	Omits confusing (medical and/or technology) jargon	1.0	0.5	1.0		
	User profile setup	Provides easy setup of user profile, e.g. option to login via social media account	1.0	1.0	0.0		
	Offline mode	Operates core functionality in offline mode	1.0	1.0	1.0		
	Reminders	Enables users to set reminders	0.5	0.5	0.5		
	Subtotal		**5.0**	**4.0**	**3.5**	**0.74**	**12.5**
Information Management	Statistics	Permits analysis of clinical data e.g. produces statistics, graphs	0.5	0.5	0.5		
	Privacy and data security	Allows secure data input and export e.g. password management, encryption, privacy statement, cloud backup	0.5	0.5	0.5		
	Quality and accurate information	Accepts and displays correct, relevant information	0.5	0.5	1.0		
	Quantity of information	Offers concise but still comprehensive information	1.0	0.0	1.0		
	Visual information	Illustrates clear and logical charts, graphs, images, videos etc	0.5	0.5	0.5		
	Credibility	Presents credible logo and cites research	0.0	0.0	0.0		
	Subtotal		**3.0**	**2.0**	**3.5**	**0.66**	**8.5**
Total			**14.5**	**10.5**	**12.5**		**37.5/72.0**

Table 30: Scores for "Blood Pressure Log (bPresso)" V3.6, by Freshware (Android, rated July 2017)

Construct	Variable	ACDC Survey Questions	Rater 1	Rater 2	Rater 3	Original -> Adjusted ICC	Original -> Adjusted Total
Engagement	Gamification	Contains gaming principles (such as digital rewards, prizes, leaderboards, badges, aggregated readings or competitions)	0.0	0.0	0.0		
	Customisation	Permits customisation of features (e.g. sound, content, notifications	1.0	1.0	0.5		
	Interactivity	Allows free-text reflections alongside clinical data	1.0	1.0	0.5		
	Engagement through use of plug-ins	Connects with a peripheral device	0.0	0.0	0.0		
	Self-awareness	Encourages user to develop self-reflection and/or increased self-awareness	0.0	0.5	0.5		
	Positive behaviour change	Encourages positive self-care practices e.g. using reminders, tips or social influences?	0.5	0.0	0.5		
	Subtotal		**2.5**	**2.5**	**2.0**	**0.84**	**7.0**
Functionality	Health warnings	Produces warnings about, or highlights, out-of-range readings	0.5	1.0	1.0		
	Feedback	Provides tactile, visual and/or sound feedback	0.5	0.0	0.5		
	Structural navigation	Facilitates sequential/appropriate navigation	1.0	1.0	0.5		
	Intuitive design	Presents intuitive use e.g. identifiable data input fields, intuitive symbols, generous touch areas	1.0	1.0	0.5		
	Connection to health services	Sends or connects data to another service	0.0	0.0	0.0		

	Performance power	Responds to app features (functions) and components (buttons/menus)	1.0	1.0	0.5		
	Subtotal		**4.0**	**4.0**	**3.0**	**0.81**	**11.0**
Ease of Use	Holistic usability	Captures self-management tasks easily in a single app	1.0	1.0	1.0		
	Automation	Facilitates automation of tasks e.g. pre-populated fields, suggestions based on inputs, management of medical appointments, automated customer service	0.5	0.0	0.0		
	Medical and technical jargon	Omits confusing (medical and/or technology) jargon	1.0	1.0	1.0		
	User profile setup	Provides easy setup of user profile, e.g. option to login via social media account	1.0	0.5	0.5		
	Offline mode	Operates core functionality in offline mode	1.0	1.0	1.0		
	Reminders	Enables users to set reminders	0.5	1.0	0.5		
	Subtotal		**5.0**	**4.5**	**4.0**	**0.87**	**13.5**
Information Management	Statistics	Permits analysis of clinical data e.g. produces statistics, graphs	0.5	1.0	0.5		
	Privacy and data security	Allows secure data input and export e.g. password management, encryption, privacy statement, cloud backup	1.0	0.5	1.0		
	Quality and accurate information	Accepts and displays correct, relevant information	1.0	1.0	1.0		
	Quantity of information	Offers concise but still comprehensive information	0.5	0.5	0.0		
	Visual information	Illustrates clear and logical charts, graphs, images, videos etc	1.0	1.0	0.5		
	Credibility	Presents credible logo and cites research	0.5	0.0	0.0		
	Subtotal		**4.5**	**4.0**	**3.0**	**0.79**	**11.5**
Total			**16.0**	**15.0**	**12.0**		**43.0/72.0**

Table 31: Scores for “Blood Pressure Diary” V3.1, by FRUCT (Android, rated July 2017)

Construct	Variable	ACDC Survey Questions	Rater 1	Rater 2	Rater 3	Original -> Adjusted ICC	Original -> Adjusted Total
Engagement	Gamification	Contains gaming principles (such as digital rewards, prizes, leaderboards, badges, aggregated readings or competitions)	0.0	0.0	0.0		
	Customisation	Permits customisation of features (e.g. sound, content, notifications	0.0	0.0	0.0		
	Interactivity	Allows free-text reflections alongside clinical data	1.0	1.0	0.5		
	Engagement through use of plug-ins	Connects with a peripheral device	0.0	0.5	0.0		
	Self-awareness	Encourages user to develop self-reflection and/or increased self-awareness	0.5	0.5	0.5		
	Positive behaviour change	Encourages positive self-care practices e.g. using reminders, tips or social influences?	0.0	0.0	0.0		
	Subtotal		**1.5**	**2.0**	**1.0**	**0.93**	**4.5**
Functionality	Health warnings	Produces warnings about, or highlights, out-of-range readings	0.5	0.5	0.5		
	Feedback	Provides tactile, visual and/or sound feedback	0.0	0.0	0.0		
	Structural navigation	Facilitates sequential/appropriate navigation	1.0	0.5	0.5		
	Intuitive design	Presents intuitive use e.g. identifiable data input fields, intuitive symbols, generous touch areas	1.0	1.0	0.5		
	Connection to health services	Sends or connects data to another service	0.0	0.0	0.0		

	Performance power	Responds to app features (functions) and components (buttons/menus)	1.0	1.0	1.0		
	Subtotal		**3.5**	**3.0**	**2.5**	**0.95**	**9.0**
Ease of Use	Holistic usability	Captures self-management tasks easily in a single app	1.0	1.0	1.0		
	Automation	Facilitates automation of tasks e.g. pre-populated fields, suggestions based on inputs, management of medical appointments, automated customer service	0.5	1.0	0.5		
	Medical and technical jargon	Omits confusing (medical and/or technology) jargon	1.0	0.5	1.0		
	User profile setup	Provides easy setup of user profile, e.g. option to login via social media account	0.5	0.5	0.5		
	Offline mode	Operates core functionality in offline mode	1.0	1.0	1.0		
	Reminders	Enables users to set reminders	0.0	0.0	0.0		
	Subtotal		**4.0**	**4.0**	**4.0**	**0.92**	**12.0**
Information Management	Statistics	Permits analysis of clinical data e.g. produces statistics, graphs	0.5	0.5	0.5		
	Privacy and data security	Allows secure data input and export e.g. password management, encryption, privacy statement, cloud backup	0.5	1.0	0.5		
	Quality and accurate information	Accepts and displays correct, relevant information	1.0	0.5	0.5		
	Quantity of information	Offers concise but still comprehensive information	0.5	0.0	0.0		
	Visual information	Illustrates clear and logical charts, graphs, images, videos etc	1.0	0.5	1.0		
	Credibility	Presents credible logo and cites research	0.5	0.0	0.0		
	Subtotal		**4.0**	**2.5**	**2.5**	**0.75**	**9.0**
Total			**13.0**	**11.5**	**10.0**		**34.5/72.0**

Table 32: Scores for “Blood Pressure” V3.12.05, by Klimaszewski Szymon (Android, rated July 2017)

Construct	Variable	ACDC Survey Questions	Rater 1	Rater 2	Rater 3	Original -> Adjusted ICC	Original -> Adjusted Total
Engagement	Gamification	Contains gaming principles (such as digital rewards, prizes, leaderboards, badges, aggregated readings or competitions)	0.0	0.0	0.0		
	Customisation	Permits customisation of features (e.g. sound, content, notifications	0.0	0.0	0.0		
	Interactivity	Allows free-text reflections alongside clinical data	1.0	1.0	0.5		
	Engagement through use of plug-ins	Connects with a peripheral device	0.0	0.5	0.0		
	Self-awareness	Encourages user to develop self-reflection and/or increased self-awareness	0.5	0.5	0.5		
	Positive behaviour change	Encourages positive self-care practices e.g. using reminders, tips or social influences?	0.0	0.0	0.0		
	Subtotal		**1.5**	**2.0**	**1.0**	**0.78**	**4.5**
Functionality	Health warnings	Produces warnings about, or highlights, out-of-range readings	0.5	0.5	0.5		
	Feedback	Provides tactile, visual and/or sound feedback	0.5	0.0	0.5		
	Structural navigation	Facilitates sequential/appropriate navigation	0.5	0.5	0.5		
	Intuitive design	Presents intuitive use e.g. identifiable data input fields, intuitive symbols, generous touch areas	0.5	1.0	1.0		
	Connection to health services	Sends or connects data to another service	0.5	0.5	0.0		

	Performance power	Responds to app features (functions) and components (buttons/menus)	1.0	1.0	1.0		
	Subtotal		**3.5**	**3.5**	**3.5**	**0.78**	**10.5**
Ease of Use	Holistic usability	Captures self-management tasks easily in a single app	1.0	1.0	1.0		
	Automation	Facilitates automation of tasks e.g. pre-populated fields, suggestions based on inputs, management of medical appointments, automated customer service	0.5	1.0	0.5		
	Medical and technical jargon	Omits confusing (medical and/or technology) jargon	1.0	1.0	1.0		
	User profile setup	Provides easy setup of user profile, e.g. option to login via social media account	0.5	0.5	0.5		
	Offline mode	Operates core functionality in offline mode	1.0	1.0	0.5		
	Reminders	Enables users to set reminders	0.5	0.5	0.5		
	Subtotal		**4.5**	**5.0**	**4.0**	**0.84**	**13.5**
Information Management	Statistics	Permits analysis of clinical data e.g. produces statistics, graphs	1.0	1.0	0.5		
	Privacy and data security	Allows secure data input and export e.g. password management, encryption, privacy statement, cloud backup	1.0	1.0	0.5		
	Quality and accurate information	Accepts and displays correct, relevant information	1.0	1.0	0.5		
	Quantity of information	Offers concise but still comprehensive information	0.5	0.5	0.5		
	Visual information	Illustrates clear and logical charts, graphs, images, videos etc	1.0	0.5	0.5		
	Credibility	Presents credible logo and cites research	0.5	0.0	0.0		
	Subtotal		**5.0**	**4.0**	**2.5**	**0.86**	**11.5**
Total			**14.5**	**14.5**	**11.0**		**40.0/72.0**

Table 33: Scores for “Diabetes Diary, Glucose, Insulin Monitor (Laborom)” V2.1.7, by xHealth (Android, rated July 2017)

Construct	Variable	ACDC Survey Questions	Rater 1	Rater 2	Rater 3	Original -> Adjusted ICC	Original -> Adjusted Total
Engagement	Gamification	Contains gaming principles (such as digital rewards, prizes, leaderboards, badges, aggregated readings or competitions)	0.0	0.0	0.0		
	Customisation	Permits customisation of features (e.g. sound, content, notifications	0.5	0.0	0.5		
	Interactivity	Allows free-text reflections alongside clinical data	1.0	1.0	1.0		
	Engagement through use of plug-ins	Connects with a peripheral device	0.0	0.0	0.0		
	Self-awareness	Encourages user to develop self-reflection and/or increased self-awareness	1.0	0.0	0.5		
	Positive behaviour change	Encourages positive self-care practices e.g. using reminders, tips or social influences?	0.5	0.0	0.5		
	Subtotal		**3.0**	**1.0**	**2.5**	**0.88**	**6.5**
Functionality	Health warnings	Produces warnings about, or highlights, out-of-range readings	0.0	0.5	0.0		
	Feedback	Provides tactile, visual and/or sound feedback	0.5	0.0	0.0		
	Structural navigation	Facilitates sequential/appropriate navigation	1.0	0.5	1.0		
	Intuitive design	Presents intuitive use e.g. identifiable data input fields, intuitive symbols, generous touch areas	1.0	1.0	1.0		
	Connection to health services	Sends or connects data to another service	0.5	0.5	0.0		

	Performance power	Responds to app features (functions) and components (buttons/menus)	1.0	1.0	0.5		
	Subtotal		**4.5**	**3.5**	**2.5**	**0.85**	**10.5**
Ease of Use	Holistic usability	Captures self-management tasks easily in a single app	1.0	1.0	1.0		
	Automation	Facilitates automation of tasks e.g. pre-populated fields, suggestions based on inputs, management of medical appointments, automated customer service	0.5	0.0	0.0		
	Medical and technical jargon	Omits confusing (medical and/or technology) jargon	1.0	0.5	1.0		
	User profile setup	Provides easy setup of user profile, e.g. option to login via social media account	1.0	1.0	0.5		
	Offline mode	Operates core functionality in offline mode	1.0	1.0	1.0		
	Reminders	Enables users to set reminders	1.0	0.5	0.5		
	Subtotal		**5.5**	**4.0**	**4.0**	**0.86**	**13.5**
Information Management	Statistics	Permits analysis of clinical data e.g. produces statistics, graphs	1.0	0.5	1.0		
	Privacy and data security	Allows secure data input and export e.g. password management, encryption, privacy statement, cloud backup	1.0	0.5	0.5		
	Quality and accurate information	Accepts and displays correct, relevant information	0.5	0.5	0.0		
	Quantity of information	Offers concise but still comprehensive information	0.5	0.0	0.0		
	Visual information	Illustrates clear and logical charts, graphs, images, videos etc	0.5	0.5	1.0		
	Credibility	Presents credible logo and cites research	0.0	0.0	0.0		
	Subtotal		**3.5**	**2.0**	**2.5**	**0.80**	**8.0**
Total			**16.5**	**10.5**	**11.5**		**38.5/72.0**

Table 34: Scores for “Health Report Daily” V2.2.4, by Elapse Technologies (Android, rated July 2017)

Construct	Variable	ACDC Survey Questions	Rater 1	Rater 2	Rater 3	Original -> Adjusted ICC	Original -> Adjusted Total
Engagement	Gamification	Contains gaming principles (such as digital rewards, prizes, leaderboards, badges, aggregated readings or competitions)	0.0	0.0	0.0		
	Customisation	Permits customisation of features (e.g. sound, content, notifications	0.5	0.5	0.0		
	Interactivity	Allows free-text reflections alongside clinical data	0.0	1.0	0.5		
	Engagement through use of plug-ins	Connects with a peripheral device	0.0	0.0	0.0		
	Self-awareness	Encourages user to develop self-reflection and/or increased self-awareness	0.0	0.0	0.0		
	Positive behaviour change	Encourages positive self-care practices e.g. using reminders, tips or social influences?	0.0	0.0	0.0		
	Subtotal		**0.5**	**1.5**	**0.5**	**0.89**	**2.5**
Functionality	Health warnings	Produces warnings about, or highlights, out-of-range readings	0.0	0.0	0.0		
	Feedback	Provides tactile, visual and/or sound feedback	0.0	0.0	0.0		
	Structural navigation	Facilitates sequential/appropriate navigation	0.0	0.0	0.0		
	Intuitive design	Presents intuitive use e.g. identifiable data input fields, intuitive symbols, generous touch areas	0.0	0.5	0.0		
	Connection to health services	Sends or connects data to another service	0.5	0.0	0.0		

	Performance power	Responds to app features (functions) and components (buttons/menus)	1.0	0.5	1.0		
	Subtotal		**1.5**	**1.0**	**1.0**	**0.85**	**3.5**
Ease of Use	Holistic usability	Captures self-management tasks easily in a single app	1.0	1.0	1.0		
	Automation	Facilitates automation of tasks e.g. pre-populated fields, suggestions based on inputs, management of medical appointments, automated customer service	0.0	0.0	0.0		
	Medical and technical jargon	Omits confusing (medical and/or technology) jargon	1.0	0.0	0.5		
	User profile setup	Provides easy setup of user profile, e.g. option to login via social media account	0.0	0.0	0.0		
	Offline mode	Operates core functionality in offline mode	1.0	1.0	1.0		
	Reminders	Enables users to set reminders	0.0	0.0	0.0		
	Subtotal		**3.5**	**2.0**	**2.5**	**0.94**	**8.0**
Information Management	Statistics	Permits analysis of clinical data e.g. produces statistics, graphs	0.5	0.5	1.0		
	Privacy and data security	Allows secure data input and export e.g. password management, encryption, privacy statement, cloud backup	0.0	0.0	0.0		
	Quality and accurate information	Accepts and displays correct, relevant information	0.5	0.0	0.0		
	Quantity of information	Offers concise but still comprehensive information	0.0	0.0	0.0		
	Visual information	Illustrates clear and logical charts, graphs, images, videos etc	0.5	0.0	0.5		
	Credibility	Presents credible logo and cites research	0.0	0.0	0.0		
	Subtotal		**1.5**	**0.5**	**1.5**	**0.82**	**3.5**
Total			**7.0**	**4.0**	**5.5**		**16.5/72.0**

Table 35: Scores for “Control Tension” V1.0.2, by Les Laboratoires Servier (Android, rated July 2017)

Construct	Variable	ACDC Survey Questions	Rater 1	Rater 2	Rater 3	Original -> Adjusted ICC	Original -> Adjusted Total
Engagement	Gamification	Contains gaming principles (such as digital rewards, prizes, leaderboards, badges, aggregated readings or competitions)	0.0	0.0	0.0		
	Customisation	Permits customisation of features (e.g. sound, content, notifications	0.0	0.0	0.0		
	Interactivity	Allows free-text reflections alongside clinical data	0.0	0.0	0.0		
	Engagement through use of plug-ins	Connects with a peripheral device	0.0	0.0	0.0		
	Self-awareness	Encourages user to develop self-reflection and/or increased self-awareness	0.5	0.0	0.0		
	Positive behaviour change	Encourages positive self-care practices e.g. using reminders, tips or social influences?	0.5	0.5	0.0		
	Subtotal		**1.0**	**0.5**	**0.0**	**0.57**	**1.5**
Functionality	Health warnings	Produces warnings about, or highlights, out-of-range readings	0.0	0.0	0.0		
	Feedback	Provides tactile, visual and/or sound feedback	0.0	0.0	0.0		
	Structural navigation	Facilitates sequential/appropriate navigation	0.5	0.0	0.0		
	Intuitive design	Presents intuitive use e.g. identifiable data input fields, intuitive symbols, generous touch areas	0.5	0.5	0.5		
	Connection to health services	Sends or connects data to another service	0.5	0.5	0.0		

	Performance power	Responds to app features (functions) and components (buttons/menus)	1.0	0.5	1.0		
	Subtotal		**2.5**	**1.5**	**1.5**	**0.88**	**5.5**
Ease of Use	Holistic usability	Captures self-management tasks easily in a single app	1.0	0.5	1.0		
	Automation	Facilitates automation of tasks e.g. pre-populated fields, suggestions based on inputs, management of medical appointments, automated customer service	0.0	0.0	0.0		
	Medical and technical jargon	Omits confusing (medical and/or technology) jargon	1.0	1.0	1.0		
	User profile setup	Provides easy setup of user profile, e.g. option to login via social media account	0.0	0.0	0.0		
	Offline mode	Operates core functionality in offline mode	1.0	1.0	1.0		
	Reminders	Enables users to set reminders	0.5	0.5	0.0		
	Subtotal		**3.5**	**3.0**	**3.0**	**0.95**	**9.5**
Information Management	Statistics	Permits analysis of clinical data e.g. produces statistics, graphs	1.0	0.5	0.5		
	Privacy and data security	Allows secure data input and export e.g. password management, encryption, privacy statement, cloud backup	0.0	0.5	0.5		
	Quality and accurate information	Accepts and displays correct, relevant information	0.5	0.5	0.0		
	Quantity of information	Offers concise but still comprehensive information	1.0	1.0	0.0		
	Visual information	Illustrates clear and logical charts, graphs, images, videos etc	1.0	0.5	0.5		
	Credibility	Presents credible logo and cites research	1.0	0.5	0.0		
	Subtotal		**4.5**	**3.5**	**1.5**	**0.70**	**9.5**
Total			**11.5**	**8.5**	**6.0**		**26.0/72.0**

Table 36: Scores for "Blood Glucose Manager" V1.2.1, by Root93 (Android, rated July 2017)

Construct	Variable	ACDC Survey Questions	Rater 1	Rater 2	Rater 3	Original -> Adjusted ICC	Original -> Adjusted Total
Engagement	Gamification	Contains gaming principles (such as digital rewards, prizes, leaderboards, badges, aggregated readings or competitions)	0.0	0.0	0.0		
	Customisation	Permits customisation of features (e.g. sound, content, notifications	0.5	0.5	0.5		
	Interactivity	Allows free-text reflections alongside clinical data	1.0	1.0	0.0		
	Engagement through use of plug-ins	Connects with a peripheral device	0.0	0.0	0.0		
	Self-awareness	Encourages user to develop self-reflection and/or increased self-awareness	0.5	0.0	0.0		
	Positive behaviour change	Encourages positive self-care practices e.g. using reminders, tips or social influences?	0.0	0.0	0.0		
	Subtotal		**2.0**	**1.5**	**0.5**	**0.97**	**4.0**
Functionality	Health warnings	Produces warnings about, or highlights, out-of-range readings	0.5	0.5	0.0		
	Feedback	Provides tactile, visual and/or sound feedback	0.5	0.5	0.0		
	Structural navigation	Facilitates sequential/appropriate navigation	0.5	0.5	0.0		
	Intuitive design	Presents intuitive use e.g. identifiable data input fields, intuitive symbols, generous touch areas	0.5	0.5	0.0		
	Connection to health services	Sends or connects data to another service	0.0	0.0	0.0		

	Performance power	Responds to app features (functions) and components (buttons/menus)	1.0	1.0	1.0		
	Subtotal		**3.0**	**3.0**	**1.0**	**0.93**	**7.0**
Ease of Use	Holistic usability	Captures self-management tasks easily in a single app	0.5	0.5	0.0		
	Automation	Facilitates automation of tasks e.g. pre-populated fields, suggestions based on inputs, management of medical appointments, automated customer service	0.0	0.0	0.0		
	Medical and technical jargon	Omits confusing (medical and/or technology) jargon	1.0	1.0	1.0		
	User profile setup	Provides easy setup of user profile, e.g. option to login via social media account	0.5	0.0	0.5		
	Offline mode	Operates core functionality in offline mode	0.5	1.0	1.0		
	Reminders	Enables users to set reminders	0.0	0.0	0.0		
	Subtotal		**2.5**	**2.5**	**2.5**	**0.90**	**7.5**
Information Management	Statistics	Permits analysis of clinical data e.g. produces statistics, graphs	0.5	0.5	0.0		
	Privacy and data security	Allows secure data input and export e.g. password management, encryption, privacy statement, cloud backup	0.0	0.0	0.0		
	Quality and accurate information	Accepts and displays correct, relevant information	1.0	0.5	0.0		
	Quantity of information	Offers concise but still comprehensive information	0.5	0.0	1.0		
	Visual information	Illustrates clear and logical charts, graphs, images, videos etc	0.5	0.0	0.0		
	Credibility	Presents credible logo and cites research	0.5	0.0	0.0		
	Subtotal		**3.0**	**1.0**	**1.0**	**0.79**	**5.0**
Total			**10.5**	**8.0**	**5.0**		**23.5/72.0**

Table 37 summarises scores of all rated hypertension apps, with the highest score being 56.5 and lowest 15.0 out of a possible 72.0. The arbitrary 80% cut-off score to identify apps that might be suitable for clinical use is 57.6, as outlined in the asthma sub-study (Section 4.5.3). In a clinical trial setting, the principal investigator typically decides whether the highest-scoring app, 1.1 points below the cut off in this hypertension circumstance, will proceed as the app of choice; however, proceeding with such an app is not recommended as it compromises the protocol's integrity.

Table 37: Summary of Rated App Scores

App Name*	Version**	Platform	Score (out of 72.0)	Mode of Rating***
iOS				
"HoMedics"	2.4.3.2	iOS	37.5	Consensus
"Heart Sure"	2.0.1	iOS	24.0	Consensus
"HeartStar Blood Pressure Monitor"	7.7.5	iOS	44.5	Individual
"Blood Pressure Companion Free"	3.3.3	iOS	44.5	Individual
"Monitor My BP for iPhone and iPad"	2.1.2	iOS	25.5	Individual
"Tactio Health"	2.2	iOS	56.5	Individual
"Blood Pressure - Smart Blood Pressure"	1.65.1	iOS	48.5	Individual
Android				
"Blood Pressure Monitor" (Boost)	2.0	Android	18.0	Consensus
"Blood Pressure Monitor (Timevy)"	1.3.4	Android	15.0	Consensus
"Blood Pressure Log (bPresso)"	3.6	Android	43.0	Individual
"Blood Pressure Diary (FRUCT)"	3.1	Android	34.5	Individual
"Blood Pressure" (Klimaszewski Szymon)	3.12.05	Android	40.0	Individual
"Diabetes Diary, Glucose, Insulin Monitor (Laborom)"	2.1.7	Android	38.5	Individual
"Health Report Daily"	2.2.4	Android	16.5	Individual
"Control Tension"	1.0.2	Android	26.0	Individual
"Blood Glucose Manager"	1.2.1	Android	23.5	Individual

*Issues with rating such as access code requirements and prompts for overseas mobile numbers to permit app usage have reduced the initially-shortlisted 10 iOS and 21 Android apps to seven and nine respectively.
**All apps were rated between 08 June 2017 and 13 July 2017
***'Individual' = three raters independently with a moderation meeting where required; 'Consensus' = single meeting of three raters

Table 38 provides collated raw (unmoderated) average scores across all independently-assessed apps for raters 1, 2 and 3. The variability between raters' total scores ranged from 1.5 to 7.0 out of 24.0 for the hypertension sub-study. Raters 1 and 3 displayed closer scores compared to rater 2. No particular rater demonstrated consistently higher or lower scores than another.

Table 38: Unmoderated Total Scores for Individually-rated Hypertension Apps

Unmoderated Average App Score	Rater 1	Rater 2	Rater 3	Range
iOS				
"HeartStar Blood Pressure Monitor"	15.0	14.0	15.5	**1.5**
"Blood Pressure Companion Free"	16.0	12.5	16.0	**3.5**
"Monitor My BP for iPhone and iPad"	9.5	6.5	9.5	**3.0**
"Tactio Health"	20.5	16.0	20.0	**4.5**
"Blood Pressure - Smart Blood Pressure (SmartBP) BP Tracker"	18.5	11.5	18.5	**7.0**
Android				
"Diabetes and Blood Pressure Log"	14.5	10.5	12.5	**4.0**
"Blood Pressure Log (bPresso) "	16.0	15.0	12.0	**4.0**
"Blood Pressure Diary (FRUCT) "	13.0	11.5	10.0	**3.0**
"Blood Pressure (Klimaszewski Szymon)"	14.5	14.5	11.0	**3.5**
"Diabetes Diary, Glucose, Insulin Monitor (Laborom)"	16.5	10.5	11.5	**6.0**
"Health Report Daily"	7.0	4.0	5.5	**3.0**
"Control Tension"	11.5	8.5	6.0	**5.5**
"Blood Glucose Manager"	10.5	8.0	5.0	**5.5**

*All apps were rated between 08 June 2017 and 13 July 2017

**'Individual' = three raters independently with a moderation meeting where required; 'Consensus' = single meeting of three raters

5.5.4 Combined Asthma and Hypertension Results

Table 39 summarises the highest and lowest scores for both asthma and hypertension sub-studies. "Tactio Health" (56.5/72.0) presents the closest score to the arbitrary 80% cut-off of 57.6.

Table 39: Summary of Highest/Lowest scores for both Sub-studies, per platform

App Name	**Version***	**Platform**	**Score (out of 72.0)**	**Mode of Rating****
Highest Asthma App Scores				
"AsthmaMD"	1.7	Android	47.0	Individual
"Asthma Patient Companion"	2.26.8	iOS	34.5	Consensus
Highest Hypertension App Scores				
"Tactio Health"	2.2	iOS	56.5	Individual
"Blood Pressure Log"	3.6	Android	43.0	Individual
Lowest Asthma App Scores				
"Asthma Tracker"	2.0.1	iOS	22.0	Individual
"myPeakFlow"	1.0.005	Android	10.5	Individual
Lowest Hypertension App Scores				
"Blood Pressure Monitor (Timevy)"	1.3.4	Android	15.0	Consensus
"Heart Sure"	2.0.1	iOS	24.0	Consensus

*Version was the latest at time of shortlisting

Table 40 provides a comparison between the number of shortlisted apps (i.e. retained through the shortlisting flowchart) and the final number subjected to assessment and rating (i.e. following further elimination of apps upon download and initial trial). It subsequently became evident some shortlisted apps required further authentication before use such as a particular access or activation code as identified in Section 5.6.1.

Table 40: Comparison of Shortlisted verse Retained and Rated Apps between two sub-studies

	iOS Asthma Apps	**Android Asthma Apps**	**iOS Hypertension Apps**	**Android Hypertension Apps**
Shortlisted	6	8	10	21
Retained and rated	3	7	7	10

5.6 Discussion

5.6.1 Adequacy of the Protocol

The purpose of this sub-study was to validate the ACDC in another disease state by identifying and assessing hypertension self-management apps for their overall quality and suitability for use in clinical settings. Overall, the ACDC protocol provided repeatable results in the hypertension sub-study compared to the evaluation of asthma self-management apps.

The following section presents a critique of the protocol when applied to apps for consumers' self-monitoring of their blood pressure. As per the asthma sub-study, this section is structured according to the three phases described in the published version of the protocol.[110]

5.6.1.1 Shortlisting Process

The use of a PRISMA-inspired flow diagram[110] as a shortlisting process for hypertension apps was found to be highly effective for filtering hundreds of apps, using criteria including duplicate and non-English language removal, relevance, provision of clinical management, last update status and cost. This process generated a shortlist of 31 hypertension apps (10 iOS and 21 Android) to assess for quality and suitability for use in clinical settings. An additional criterion was added to the Screening swimlane for broader applicability to accommodate the notable number of Conference/Journal apps. There was a greater proportion of novelty or 'prank' hypertension apps than amongst the asthma apps, with equal number of duplicate apps.

Once apps were shortlisted, further screening and elimination was required, as some apps required specific set-up data, such as a hospital-provided access code "AsthmaPortal" from Singapore or an (African) phone number to send an activation code ("AfyaPap"), to operate. This finding was not unexpected. In the asthma sub-study, a number of apps (three iOS and one Android) were also eliminated post-shortlisting for similar reasons.

The flowchart can only represent common and predictable criteria for eliminating apps, and can be modified for each use. After testing the flowchart for apps used in two disease states, it appeared to be robust, yet the group of shortlisted hypertension apps presented some unique challenges that had not appeared in the previous trial: nearly half were not deemed operational in the local environment. Other published studies have not reported this limitation.[99,106,153,190-192]

Upon reflection, further elimination post-shortlisting is acceptable. In cases where further shortlisting is necessary, it is suggested either adding decision trees before the 'Included' swimlane or manually handling anomalies within the final shortlisted apps, which is what occurred in current study. Therefore, retention of the familiarisation trial before attempting to score apps is necessary. Post-download is the only time an access code or mobile number is identified to be requested from a source irretrievable for a general consumer. There is no description of this in the summaries about apps in the display of the search results.

Seventeen out of 31 apps remained from a total of 353 hypertension apps (101 iOS and 252 Android). Moreover, the proportion of hypertension apps retained using the flow diagram was 31/353 = 8.8%, compared to asthma apps: 14/360 = 3.9%. Following download of the apps prior to the rating exercise, these numbers changed to 17/353 = 4.8% (hypertension) and 10/360 = 2.8% (asthma).

Compared to other health app shortlisting processes,[145,146] the PRISMA-inspired filtering appeared efficient and more structured, and had a stronger evidence base. Arnhold et al. simply used the "Health and Fitness" and "Medicine" App Store® subcategories and used the automatic "sort by release date" option, in addition to app availability on both smartphone and tablet.[145] Their approach identified a 10% sample of diabetes apps in 2013, with consideration to elderly people with diabetes. For example, out of the 380 Android apps available, a random 10% sample was selected for expert usability evaluation based on four criteria: comprehensibility, presentation, usability and general characteristics. Although most of the criteria were grounded in the literature, it was not as comprehensive as the ACDC[110] or MARS.[99]

Again, consistent with published findings,[139] the Google Play™ store search yielded fewer relevant apps than the iOS App Store® and more novelty/prank apps. This is likely, since publishing via the Google Play™ store requires a comparatively less restrictive submission process, and less formal developer guidance is provided.[139] A minor addition to the flowchart's Screening swimlane assisted the hypertension app shortlisting process by adding another variable to filter through the flow diagram, namely 'conference/journal'.

5.6.1.2 Trialling Apps

In the second sub-study, the dummy patient profile was adapted to represent a consumer with Stage 1 (moderate) hypertension. This provides standardised responses to input variables required by apps, and aims to enhance consistency between and within raters when trialling data entry, as recognised by previous health app usability studies[101,147] and supported by the previous ACDC asthma sub-study. More recently during Quarter 3, 2017, the New Zealand Ministry of Health published a guidance document to assist developers of health apps.[193] Of the four frameworks reviewed in the guideline, creating a dummy profile as part of a health app checklist was unique to the ACDC.[110]

Development of a comprehensive dummy patient profile describing a user with hypertension required several iterations during the consensus rating stage, in response to input fields encountered in various apps. Over the course of shortlisting 360 hypertension apps and trialling 31 apps, the following variables were added to the profile during the consensus rating stage: rater's email address to test reporting functions, more elaborate triggers for the chronic condition, more comprehensive demographic descriptors, blood pressure monitor cuff position and location (left/right upper arm or thigh) and additional (lipid-lowering) medication and associated dosage/frequency. After trialling 31 asthma apps, only 7 iOS apps and 10 Android apps were rated due to access issues outlined in Section 5.6.1.1. Other health app studies[148,149] highlighted that dosage frequency and international drug naming conventions required consideration of the local market or geography.

Entering one week's worth of realistic in-range blood pressure and heart rate readings, followed by one week of readings representing poor control and poor monitoring of the chronic condition, again seemed plausible to test the capacity of an app to analyse readings and provide out-of-range alerts. No previous studies had reported this approach. Similar to the asthma sub-study, some hypertension apps did not allow backdating of clinical readings, meaning readings required input prospectively over two weeks. Prospective (daily) input was an opportunity to test an app's reminder function.

Again, initially five to 10 minutes was spent navigating each app's features before rating the app using the ACDC. This amount of time was deemed sufficient to gain an appreciation of app requirements before rating. Dummy data inputted at this stage was aided by the dummy profile, ensured consistent reading and demographic input and was re-examined during the rating stage to enable efficient transition through the ACDC questionnaire once rating commenced. The present findings suggest a unique dummy profile, unique to the chronic condition in question, is a valuable component of the ACDC protocol.

It is important to note inaccurate display of readings has implications for the user's clinical management. For example, one app did not transfer all manual entries into graphical format ("Health Report Daily", Android), as outlined in Section 5.6.5.

5.6.2 Scoring Reflection

In line with the asthma sub-study, Qualtrics® was utilised to facilitate scoring of each app using a three-point scale from 0.0 to 1.0 for each criterion in the ACDC. A three-point scale again worked well when rating apps for this second disease state. The length of scale had the ability to compromise ICC values because of the relative weighting of each score option in this ratio level of measurement. The scale used in both sub-studies required a value of 0 to signify 'not evident' for apps lacking certain criteria. As discussed in Section 5.5.3, the variability between raters' total scores ranged from 1.5 to 7.0 for the hypertension sub-study, compared to 0.5 to 7.0 for the asthma sub-study out of a maximum score of 24.0 (six ACDC questions x four constructs).

5.6.3 Inter-Rater Consistency

Raters 1, 2 and 3 were the same raters as for the asthma study. Moderation of scores was performed for domains with ICC values below 0.7 (low inter-rater consistency). This approach has not been reported in similar health app usability studies. There were significantly fewer moderated domain scores for the suite of hypertension apps rated individually compared to the asthma apps, presumably due to familiarity with the rating system in this repeat exercise.

“Tactio Health” and “Blood Pressure Monitor (Timevy)” represented the apps with the highest and lowest overall scores of all rated apps, respectively, these scores differing by 41.5 out of a maximum possible score of 72.0. The range for asthma apps was 36.5, with “AsthmaMD” at 47.0 and “myPeakFlow” at 10.5. For the lowest-scoring app, most essential features were too basic and expected functionalities for reports and reminders failed. Top-scoring apps featured comprehensive privacy policies, detailed user profiles, offline capability, ‘traffic light’ warning systems for readings, more advanced statistics and graphical representation of raw data, and connection to eHealth services such as Microsoft® HealthVault™ or Apple® HealthKit™. The ACDC included sub-questions to differentiate such features. Notably, there were no features in the highest-scoring apps that were not registered in the ACDC instrument, confirming the content validity of the ACDC.

5.6.4 Reflection on the App Shortlisting

Similar to search engine optimisation to optimise website ranking on popular engines such as Google™, Bing™ or Yahoo™, iOS and Android app search results can be automatically ordered by the platform based on criteria such category (medical, games etc), price, or user ratings. However, a ‘ranking’ process is also offered for developers to enhance the probability of appearing in front of the right user’s search results.[194]

A number of factors affect the ranking of search results within app store. These include:[194]

- The developer’s use of relevant keywords in the title of the app
- Appropriate use of keywords in the description of the app
- Categorisation of the app as a game or medical app
- Opportunities for (in-app) user feedback.

Competition in app stores is powerful, with celebrities such as Arnold Schwarzenegger and Liam Neeson featuring in two highly popular gaming app commercials, “Mobile Strike” and “Clash of Clans”, respectively.[195] Regarding health apps, celebrity fitness trainer Anna Kaiser released her own fitness app (“AKT On Demand”), with an on-demand streaming portal where users can speak to qualified trainers via Skype and join an interactive workout on-the-go.[196] Similarly, the health app category is competitive, with paid ads called "Search Ads" available on iOS in Australia, New Zealand, the US and the UK to 'bump up' apps in search results and gain more 'screen real estate'. This is a relatively new App Store® feature, with US$100 credit incentive for developers.[197] Free apps may rely on advertising for sustainability, but paid apps are also entitled to utilise ads, in-app purchases and other options to increase cash flow. If paid apps were included in the shortlisting process, less advertising may have been present for those apps with a 'Pro' feature. The most common form – banner ads – commonly disappear with a paid version, providing a less interrupting user experience. However, it is not guaranteed all paid apps are free from any form of advertising. Well before Apple, in July 2015, Google's official blog site announced internationally that Search Ads would feature in the Google Play™ store.[198] The uptake of useful clinical apps can be compromised if developers do not use this feature.

5.6.5 Reflection on the Shortlisted Apps

Another study into mobile health apps for self-management of a chronic condition identified a significant proportion of apps (56 of 65 diabetes apps) either lacked "even minimal requirements" or "did not work properly."[199] "Minimum requirements" for diabetes self-management involve entering and systematically tracking "glucose and insulin entry." This is consistent with the present findings relating to asthma and hypertension apps. This further strengthens the premise for scientific literature to guide the construction of health apps, with pilot testing on a sample cohort increasing sustained engagement in the cluttered app marketplace.[65]

Empirical observations regarding both hypertension and asthma apps are offered below and aligned to the four ACDC construct as best possible:

Engagement:

- An app displaying advertising on the top section of the screen was unappealing to the three raters. Data entry for one app was delayed until that banner ad appeared.

- Setting goals to attain target blood pressure readings (e.g. 130/85 with 75 bpm heart rate) may increase persistence,[65] and was welcomed by the raters.

- Voice-controlled entries, offered only by one of the apps, was a novel feature of one app (“Diabetes and Blood Pressure Log”, Android). This functionality required additional permission to access the smartphone’s microphone.

- “Submit an idea” and the “Select Medication Database” via country were unique features, enabling a more personal self-care experience. However, the list of countries was limited and did not include Australia, New Zealand or the US.

- An invitation code for friends and family to join one’s self-care journey was well received by the raters, promoting positive self-care practices via social influences. This was reflected in the ACDC in question 2.6, relating to Engagement.

- The capacity to document notes alongside blood pressure readings was welcomed, but could be improved by linking key words to map a pattern of behaviour, for example, tracking of days in which ‘smoking’ or ‘stress’ was entered. No shortlisted app featured this, but could be incorporated using a simple in-app JavaScript query.

Functionality

- No shortlisted app provided alerts for gaps in the frequency of documented blood pressure readings, although a colour-coded system differentiated out-of-range readings in a number of apps. Ideally, an app should provide both features. No published checklist differentiates such features.

- The traffic light colour-coding system to categorise stage/control of hypertension was not adopted by all apps. Some used different shades of red to signify mild to high hypertension, which could lead to confusion (e.g. “BPresso”, Android), but colour coding could apply to numerical data, graphical outputs or both.

- Some apps such as “MyDiary4Health” (Android) presented a cluttered initial home screen, which may be off-putting to health consumers. Hyperlinked images positioned too close to data entry fields linking consumers to a webpage from the initial display screen could benefit from revision.

- Apps permitting adjustment of blood pressure ranges, such as changing an optimal range from 110/75 to 120/80, provided flexibility to reflect regional guidelines and doctor's advice ("BPresso" and "Diabetes and Blood Pressure Log", Android).

- Whilst most hypertension apps provided a free text-based reminder feature for self-monitoring and/or medication, fewer provided an opportunity to detail changes in dosage, unit of measurement, frequency and varied weekend times per reminder.

Ease of Use

- Recalling previous measurements as default values for future measurements saves the consumer time.

Information Management

- Legibility and accuracy of graphical output for tablet and smartphones remains an issue with both asthma and hypertension apps. One shortlisted Android app ("Diabetes and Blood Pressure Log" by Cooey Technologies) required a restart before updated manual entries could be graphically represented. For both asthma and hypertension sub-studies, the same devices were used, i.e. Android smartphones for all Android apps and iPads for all iOS apps except for one asthma app requiring the latest iOS version, where an iPhone 6 was used. Functionality to produce user-friendly graphical output does not necessarily increase the app's file size – it is a matter of optimising the code for size awareness. Improving graphical output, in line with consumer expectations for tracking/monitoring their progress, is recommended by the author of this thesis, and supported by literature.[65]

- Additionally, legibility and size of mobile device screens should not be prohibitive in creating graph views or buttons. Most programming languages contain libraries for size-aware commands, such as ‘react-window-size’ through the ‘npm’ JavaScript package manager.

- Some apps, such as “BP Companion Free” (iOS), did not accept backdated entries, placing onus on daily self-care readings. For some people, it is not always possible to input daily peak flow readings. However, this feature can serve as a timely reminder for daily readings. A greater proportion of hypertension apps accepted backdated entries compared to the asthma apps.

- Recognition of common Australian medication brand names (e.g. Coversyl®; perindopril) via drop-down menus proved confusing for shortlisted apps with a dedicated medication entry feature, such as “BPresso Blood Pressure Log” by Freshware (Android).

- Consumer-friendly export file types were not universally provided. One shortlisted app sent a blank email to the user when data export was requested.

- One app accepted a higher diastolic reading than the systolic reading, which is not physiologically possible (“Blood Glucose Manager”).

- Inconsistent naming conventions in the Google Play™ store was not welcomed by all three raters. For example, “Smart Health & Patient Support” would be displayed on an Android smartphone as “Laborom”. This app also displayed “mmHg” and “hgmm” as blood pressure units, and included the Hungarian spelling for tablet and other contractions. Moreover, not exemplary for international usage, if it met the scoring threshold but still decipherable.

- Additional typographical errors included “Recorded data ***isn’t*** exist”, “***manege*** data (“Blood Glucose Manager” by Root93), potentially affecting users’ perception of the quality of the app.

- One app did not transfer all manual entries into graphical format (“Health Report Daily”, Android).

- The format of exported data, exclusively XML files containing raw blood pressure data, can be difficult to interpret by consumers and is not universally compatible with smartphone applications.

The following general functional observations fall outside the scope of the ACDC.

- The total number of shortlisted clinical hypertension apps was over double the 14 asthma apps. A greater prevalence of clinical hypertension apps was evident compared to asthma apps.

- In both sub-studies, there were more Android than iOS apps shortlisted, which may allude to Apple's more stringent app approval process compared to Android.[139] The proportion of Android apps would be even higher if duplicate apps were not deleted in favour of the iOS version.

- The PRISMA-inspired shortlisting flowchart does not have the capacity to exclude apps that require validation codes to commence usage of the app. This limits theoretical trial of apps that might have high levels of functionality, and be well suited to use in clinical settings; however, given the modest scores observed in the current suites of asthma and hypertension apps, this is unlikely.

- It is assumed that developers review existing offerings when creating new apps, in order to replicate certain features and improve upon existing apps. This practice should, over time, result in more feature-rich apps and improved quality and functionality of apps. A repeat of the shortlisting and rating of asthma and hypertension apps in several years would likely reveal a markedly different landscape of apps, and shortlisted apps with improved functionality.

Furthermore, from the 17 rated hypertension apps (from the initially-shortlisted 31 apps), only one was Australian ("Heart Sure™"). Because consumers may not necessarily consider the country of origin when searching for and downloading apps, it is recommended that apps include metric system conversion options and recognisable medication names to be 'internationally relevant'. Currently, the respective app stores in this study do not categorise apps by their country of origin. However, most apps provide a country listed for the contact option within the app store. It is not always feasible to specify the country within the app name, as it could limit the developer's market.

Shortcomings and errors encountered during the trial of apps were not communicated to the respective developer. With timely publication of the ACDC and the current findings, it is anticipated that developers would be able to access this feedback and gain insight into ideal functionality and clinical effectiveness.

5.6.6 Conclusion

In conclusion, the ACDC protocol was applied to identify, assess and rate apps for self-monitoring of hypertension, aiming to identify an app(s) that may be suitable or recommended for clinical usage. Out of 17 rated apps, only the score for "Tactio Health" (56.5/72.0) was the closest app meeting the arbitrary 80% of the maximum score required for inclusion in a clinical trial. This was 9.5 points higher than score of 47.0/72 for "AsthmaMD". "Blood Pressure Monitor" (Timevy) presented the lowest score of 15.0/72, which was also higher than "myPeakFlow", scoring 10.5/72.

Nevertheless, the ACDC protocol performed well in the replicated process, with minimal revision for this hypertension sub-study compared to the asthma sub-study. The protocol demonstrated sustained reliability and validity, as evidenced by the validation against hypertension apps, for example. Some flexibility in the protocol pertaining to the shortlisting flowchart and the dummy profile is likely to be needed during application to other medical conditions such as diabetes.

6 CHAPTER 6: Literature Review: Updates to Mobile Self-Care

6.1 Preface

This Chapter provides an update to literature via a mapping review and addresses Research Objective 4a, namely: "An updated literature review relevant to the current mobile self-care environment."

On account of the rapidly expanding literature in this field, an update to the body of knowledge is provided in this chapter in the form of a mapping review, similar to that of the published manuscript.[82] The original literature review presented an Australian-specific account of mobile self-care using apps. Despite the emergence of new apps for self-management of chronic conditions and the paucity of trials involving mobile self-care in Australia at that time, the literature search has been extended in this chapter, and presented as a mapping review.

6.2 Updates to Mobile Self-Care and Updated Search Strategy

The first modification to the original literature search is the inclusion here of international trials, including those comparing traditional paper-based methods for documentation of health data to health apps also for that purpose. The original search was limited to Australian studies to better align methods and findings to the Australian Health System and the "My Health Record" (MHR), Australia's online repository of patient health data.[200]

Secondly, only chronic conditions, as defined by the WHO, had been considered in the previous chapter.[201] The updated literature search reflects the focus on chronic conditions requiring objective data input such as peak flow or blood pressure readings. Additionally, the ACDC is specifically created for chronic conditions.[110]

Thirdly, the literature search strategy has been modified to omit conditions associated with subjective data, such as self-rating of pain/symptoms, mood or happiness scores. Objective data input refers to numerical data generated from monitoring of a chronic condition using a medical device such as peak flow or heart rate monitor. These data are a mixture of user-entered data and automatic uploads from wearables.

Finally, the database search was supplemented by a search of 'grey' literature from 2015 to December 2017, conducted by browsing particular websites, such as *Australian Pharmacist*, using the same keywords as the formal searches thus providing insight into research not indexed in the key databases and the emerging concept of blockchain in health,[202] described in Section 6.5. In particular, manual searches in *JMIR* using the same search terms coupled with a scan of "Content Update Alerts" delivered by email, were performed for the current review due to the quantity of published studies around mobile health apps. Additionally, grey literature is particularly useful in this field, as it leverages the power of social media, such as news posts and professional articles, in a timelier manner than peer-reviewed articles.

The original and updated search strategies are illustrated in Figure 12. The same databases as per the *AHR* paper[82] were interrogated, that is, MEDLINE™, ProQuest® and Global Health™ (Ovid®) databases. The omission of Cochrane reviews for this updated search was due to the time lag associated with publication of systematic reviews. Search results were merged in EndNote® and duplicates removed.

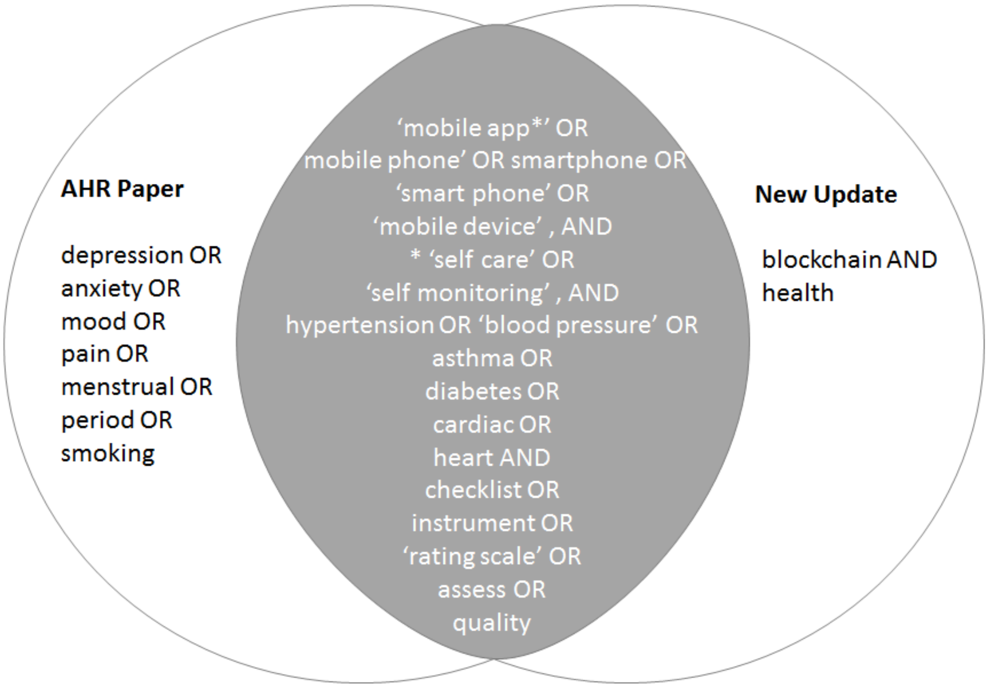


Figure 12: Search Strategy Similarities and Differences[1]

[1]Anderson K, Emmerton LM. The contribution of mobile health applications to self-management by consumers: review of published evidence. Aust Health Rev. 2015;10.1071/AH15162[doi. [Medline: 26681206]

In total, 116 articles were found from searches spanning January 2016 to January 2018, with one duplicate. Upon shortlisting via review of titles and abstracts, three trials were located, along with seven review papers located in ProQuest®. The commentary from these seven reviews were of use, and hence, these reviews were retained. A comparison of literature from the initial search to the current mapping review is provided in Table 41, representing the difference in shortlisted manuscripts from the initial *AHR* paper mapping review and the Chapter 6 update.

Table 41: Comparison of Search Results before Shortlisting

	ProQuest®	Global Health™ (Ovid®)	MEDLINE™	Cochrane®
AHR Paper[1][82]	24	3	33	4
Chapter 6 Update[2]	51	50	15	N/A

[1] January 2013 – January 2015

[2] January 2016 – January 2018

NB: Literature updates during the period January 2015 – January 2016 is presented in Section 6.3 as the foundations when creating the ACDC

6.3 Mobile Self-Care using Apps: Literature Update

Since the published literature review[82] presented in Chapter 1, the creation of the ACDC required monitoring of the international literature regarding mobile self-care. A number of literature updates were presented in the *JMIR Research Protocols*[110] paper when creating the ACDC. Specifically, literature was cited to support each question in the checklist.[110] Approximately two years (Quarter 3, 2015 – Quarter 1, 2018) has passed between acceptance for publication of the literature review and this current literature update, with numerous updates to the literature noted.

The grey literature search spanning January 2015 to December 2017 revealed an official press release in October 2017 by the New Zealand Ministry of Health, describing guidance targeted to physicians for selection of a health app for their patients.[193] The report cited and recommended four tools/checklists, including the ACDC, along with the MARS, a critique of which was included in the *JMIR Research Protocols*[110] manuscript. The other two recommended tools were a non-peer reviewed guideline, namely, the Canadian Medication Association's seven guiding principles,[203] and a peer-reviewed tool from Great Britain, namely, an 18-item Royal College of Physicians Checklist.[204] Both were targeted to equip physicians with more informed decision making to provide patients. These additional resources are critiqued below and itemised in Table 42.

The ACDC created as a core of this thesis is targeted to academics who seek an app suitable for integration in a clinical trial, or to health professionals to identify an app(s) suitable for a consumer’s use for self-monitoring. All checklists/tools from the original and updated mapping review acknowledge the importance of benchmarks for clinical apps in promoting accurate and sustainable self-care of one’s chronic condition.[99,110,203,204]

The British and Canadian app assessment tools did not seem to base checklist questions upon published evidence; for example, no source was evident for checklist questions such as: “Q1f. Is it clear what data the app needs from the user with units defined, out of range detection and a ‘clear last patient’ button?” and “Q1h. Does it seem to keep user and patient data secure and private?” in the British tool.[204] This is where the ACDC adds value when shortlisting apps for managing chronic conditions, since all questions were derived from literature and the preceding qualitative research. Of the 18 questions in the British checklist, the majority included three response options, while three questions included two response options. Two response options represents a more crude level of measurement, and can complicate ICC analysis if the tool were to be assessed by independent raters.

Additionally, the Canadian tool is a guideline that does not provide any measurable questions for physicians to follow, increasing the subjectivity of selection of apps between physicians. Without specific and objective questions, one physician may consider “Usability”, the second guiding principle, more stringently than another physician, and influencing preferences for particular apps. Exceptions to this apply when a physician might need to place emphasis on a particular characteristic; for example, usability might be more important for a health consumer with limited technological literacy. As a published guideline, it is likely suitable for use in clinical practice. Lack of quantification does, however, limit capacity to apply that guideline in clinical research. The guiding principles would require modification into a checklist for that purpose.

All identified instruments[99,110,203] acknowledge leveraging the usability of an app to enhance user engagement, as represented in Table 42. Additionally, the presence of endorsements or credentials are crucial[65] when assessing an app’s credibility, along with privacy of patient data and security of data transfer. Updates relating to the privacy of patient data are presented in Section 6.5, as blockchain data security has recently received notable attention by the Australian media in print[202] and non-print outlets relating to its application to health.

Table 42: Commonalities and Differences between Health App Checklists/Tools

	ACDC[110]	MARS[99]	Wyatt et al., 2015 (British Checklist)[204]	Canadian Medical[203] Association 2015
Themes	N = 4 Engagement Functionality Ease of Use Information Management	N = 4 Engagement Functionality Aesthetics Information	N = 3 App-Background Functionality Evidence	N = 7 Endorsement Usability Reliability Privacy/Security Conflict of Interest Fragmentation Impact
Questions (N)	24	26	18	N/A
Response options for each question (n)	3	5	2-3	N/A
Recommended raters (n)	3	2	1	1
Target audience	Academics/ researchers	App developers, researchers, and health professionals	Physicians	Physicians
Peer-reviewed (Yes/No)	Y	Y	Y	N
Publication/ source	*JMIR Research Protocols*	*JMIR mHealth and uHealth*	*Clinical Medicine* (London)	Canadian Medical Association

6.4 Self-Care Trials using Mobile Health

This section provides an update regarding self-care trials using health apps. Some studies were targeted to specific users, such as "apps on depression for Indian users"[205] or "Diabetes Applications for Arabic Speakers".[206]

While some studies into self-care have involved feedback from large numbers of volunteers, for example, 4463 participants in a diabetes study in Washington, US,[3] some mobile app self-care trials using app-based self-care[207-209] have omitted focus on the user experience. More recent searches uncovered a 2018 cardiac rehabilitation study, also in Washington,[210] reporting "patient acceptance" of a purpose-built Department of

Veterans' Affairs app, "VA FitHeart". The System Usability Scale[211] was assessed by 13 armed services veterans aged 43-75 years to compare usability of the original version (n=5) and the refined app (n=8). Additionally, "task completion success rate" was measured after usability iterations were conducted, increasing the success rate from 44% to 78%.[210] Additionally, the System Usability Scale increased from 54 to 76 out of 100. This study is a prime example of the application of theories to improve outcomes, in this case, the Unified Theory of Acceptance and Use of Technology for consumers. This theoretical approach to improve the outcomes of mobile self-care trials is what this thesis has been advocating.

A number of studies have explored the impact of technological interventions on consumers' health outcomes; these have included automated reminders (via text messaging),[212,213] trials of internet-based self-care interventions in chronic back pain,[214] mobile app-based obesity management[215] and lifestyle management for breast cancer survivors using apps.[216] There is even a home-based monitoring system for Parkinson's disease.[217] Notable deficiencies in these studies are their minimal reference to self-efficacy measures and relatively short follow-up periods.

Literature updates are presented by chronic condition below.

6.4.1 Diabetes

More recent studies on self-monitoring include a 2016 diabetes and hypertension study from India, in which consumers documented fasting plasma glucose and systolic/diastolic blood pressure during the mPower Heart Project.[218] This study provides evidence addressing gaps in previous studies with short follow-up periods; this was an 18-month study with follow-ups every three months from baseline. Complete 18-month follow-up data for 759 out of 6016 participants was achieved, revealing a mean 14.6mm Hg and 7.6mm Hg reduction in systolic and diastolic pressure, respectively. These reductions were claimed to result from participants' involvement in self-documentation of readings, along with nurse-led input of systolic/diastolic readings and fasting blood glucose readings into the "mPower Heart Project System" app.[218] Participants did not directly use the app. Additionally, a 50.0 mg/dL reduction in fasting plasma glucose was reported from baseline until the 18th month.[218] This is also the first known study to trial two chronic conditions monitored via objective data, and using a single app. Although promising results were reported, results should be validated through an RCT, as confirmed by the authors.[218]

Within the original published literature search,[82] self-management programs were found to measure only select outcomes, rather than a spectrum of outcomes relevant to conditions such as diabetes, osteoarthritis and hypertension.[9] However, more recent studies have incorporated a wider variety of measurable outcomes. For example, another diabetes study[219] recognised the value of documenting, in addition to blood sugar levels, insulin, medication and secondary factors such as diet and exercise. Although that study was published in 2013, the 2016 systematic review in which it is featured provides useful commentary around the inclusion of features based on "clinical guidance."[199] The diabetes study discovered 56 of 65 shortlisted apps did not meet basic criteria or work properly, some failing to retain longitudinal blood glucose data. This study was crucial because it determined only nine of 65 apps to be "versatile" and "successful for self-management".[219] The researchers also commented on the value of customising an app based on consumer needs, such as differentiating between Type 1 and Type 2 diabetes. This differentiation has appeared in counselling/education pages about the risk of hypoglycaemia and medication management for Type 1 diabetes compared to Type 2.[199] Upon reflection, two separate apps need not exist for Type 1 and 2 diabetes, but rather could be incorporated as an option within the user profile.

A 2016 systematic review on diabetes, originating from China, excluded studies with less than three months' follow-up. This is consistent with calls from other authors regarding longer follow-up periods.[74,199] This review included only one study from the 2016-2018 timeframe used in the present mapping review.[64] That study, from the USA, included 40 participants, equally divided into intervention and control groups and ranging from 23 to 80 years old. The three-month diabetes secure texting and virtual visits intervention (including shared screens for interactivity) lasted between 10 and 14 weeks for flexibility in participant data collection, and was built using CollaboRhythm™ software from Massachusetts Institute of Technology.[64] The mean glycated haemoglobin in the intervention group decreased by 3.2±1.5% ($p<0.0001$), and by 2.0±2.0% ($p=0.0003$) in the control group.[64]

The systematic review also conferred similarities to previously mentioned studies, such as the need to improve "patients' awareness" within the self-care paradigm[64] and risks associated with poor self-management, which is why interventions to improve health literacy are of great importance.

6.4.2 Asthma

A 2016 trial of a Californian custom-made asthma app measured Asthma Control Test scores with the use of a spirometer to calculate Forced Expiratory Volume. Sixty participants (41 female) were recruited, aged 17-82 years. Mean test scores for "Scripps Health Asthma Coach" increased from inadequate (16.6) to controlled (20.5).[74] "Scripps Health Asthma Coach" was the app used in the trial; the same app appeared during shortlisting asthma apps for ACDC rating, but required an access code, hence its exclusion from rating using the ACDC. Additionally, Forced Expiratory Volume increased by 7.9%, with corticosteroids decreasing from 0.5 to 0.3 courses, over six months. The study concurs with recommendations from Brzan et al., 2016[199] by streamlining "burdensome inputs"[199] for efficiency, ease of use and delivering counselling/education. Also mentioned as important was user customisation, such as the ability of an app to cater for triggers and establish strategies to improve medication adherence.[74] After the four-month study concluded, 72% of participants continued using the app for an additional two months. The authors concluded evidence-based content such as their provision of 48 educational videos for taking accurate readings, for example, using an inhaler and identifying common asthma triggers were key for accurate data capture.[74] Subsequently, a questionnaire was disseminated to capture data such as "user experience and satisfaction", scoring 9.3/10 for ease of use and 7.9/10 for "relevance to personal asthma plan".

A 2017 Australian "Kiss My Asthma" app study, with 20 participants from Sydney, considered a unique angle relating to mental wellbeing of young adults with asthma, referring to concepts such as "lack of autonomy" and "social disconnectedness."[220] Participants ranged from 15 to 24 years, 60% of whom were female and 90% were secondary or tertiary students. Another unique characteristic of this study were the four 2.5-hour participatory design workshops, with discussions analysed thematically to identify preferences and needs for app design and features. One key finding was consumer preference for "psychological experience" features in an app, to address mental wellbeing[220] and support users' "competence", "autonomy" and "relatedness", concepts recognised in the Self-Determination Theory.[221] This consumer-focussed strategy is in line with the arguments presented in this thesis, as it fosters self-care principles for taking ownership of one's condition[7] and thus improving the likelihood of 'success' of an app.[222] Applying principles of self-management by providing measures for consumers to take more ownership of their self-monitoring through feature-rich health apps is advocated in this thesis.[220] This is exemplified through involvement in the app co-creation process via participatory design workshops and by determining psychological needs to support sustained app usage.[221] Involving consumers during the analysis and design stages of health app development for the management of chronic conditions more accurately simulates "real life settings."[151] This is another example of where studies support app design through established literature, which is also in line with the arguments presented in this thesis. Moreover, this study adopted a social science lens on the use of apps, supplementing other more clinical studies.

6.5 Blockchain Security and Implications for Health Data

Blockchain security in health presents growing opportunity for research into medical data security and integrity. The purpose of the brief review in this section is to welcome the emerging science of blockchain security in eHealth and to establish its place within the mobile self-care ecosystem. Investigation of the science and algorithmic properties of blockchain architecture is beyond the scope of this thesis. As of January 2018, there were limited studies exploring the application of blockchain security in health.

Blockchain is a cryptographic protocol providing an immutable record of events between digital assets where master file, or ledger, is decentralised and distributed for data integrity.[223] Every action, such as the exchange of digital assets, is recorded in a distributed digital ledger, the integrity of which can be verified using 'miners' who compute algorithmic functions to prove a mathematical concept. Due to this, third parties such as merchants become increasingly redundant, and such practices have been applied in direct commerce such as via Bitcoin® transactions.[224] The process of Peer-to-Peer (P2P) transaction validation provides miners with remuneration in the form of Bitcoin.[223] This validation ensures the proof-of-work is authentic and there is no forgery of information, since it has been validated via numerous miners. With the use of blockchain technology to combat identity fraud, its application in health is an emerging and formidable information management solution. Other blockchain applications include digital rights management to prevent excessive copying of purchased online media (such as music) and the housing market to verify and transfer land titles.[225,226] Blockchain also presents an opportunity to provide digital assets such as medical records, land titles and birth certificates with integrity and security.[227] This technology asserts an immutable record for all entries, streamlining auditing of transactions.[228]

In Australia, there is support for all medical-related data to reside in individuals' MHR.[200] Therefore, new app frameworks such as HealthKit™ by Apple® will need to comply with residing data in the MHR platform for more streamlined acceptance of health data interchange. At present, very few HealthKit™ apps are available via an Australian iTunes® account. It is essential for these apps to recognise the geographies in which they operate, and cater for their users' health data management needs. Although no compulsory mandates exist for Apple® products to interface with MHR, there is, anecdotally, increasing support for integration from physicians, based on personal communication at local Australian Hackathons.

Blockchain provides an impetus to innovate data exchange between digital assets such as general practitioner or pharmacy records and the MHR. The Australian Digital Health Agency acknowledges "Secure Messaging" and proof-of-concept projects are underway to test data transfer of discharge summaries, referrals and reports.[229] Once these projects are scrutinised for compliance with security protocols, other use cases, such as data entered by consumers into mobile health apps, can be proposed.

Quantum computing is currently the largest threat to blockchain's integrity due to its computational capability of leveraging quantum bits called "qubits", handling both "0" and "1", unlike traditional "bits" which can only hold one state simultaneously.[230] However, creating such a terminal requires physicists, computer engineers and software architects years to achieve the desired effect and utilises highly unstable qubits rather than traditional "bits" in today's commerce.

In conclusion, blockchain's application has been welcomed by the author of this thesis as a reliable method to ensure data security and integrity. Implementing blockchain-compliant systems to communicate with existing patient databases presents the next challenge for health administration professionals.

6.6 Summary of Literature Updates

This chapter has presented an update to mobile self-care app literature since the initial peer-reviewed manuscript.[82] This update discovered various studies which utilise multiple interventional strategies such as educational tools to facilitate self-care using mobile apps. The advent of blockchain technology in the eHealth domain has shed light onto Information Management relating to data from self-monitoring of health conditions, and will be applied to the Concept Map in Chapter 7, depicting integration of blockchain technology to a mobile self-care ecosystem.

7 CHAPTER 7: Translational Application of Mobile Self-Care

This chapter synthesises findings from the entire thesis and applies it to a mobile self-care concept map, addressing Research Objective 4b, namely: "Derivation of a mobile self-care concept map describing the mobile self-care eco-system."

7.1 Preface

This is a data synthesis chapter presenting a process map depicting the stages of data generation (in the form of clinical readings originating from a wearable or smartphone devices), data dissemination (of clinical readings to other repositories such as the MHR[200] and data management for optimal and sustainable integration of apps in mobile self-care. This process map is the culmination of previous chapters in this thesis. The strengths and limitations of this thesis are critiqued in the subsequent Discussion Chapter 8.

Chapter 1 presented a paper published by the PhD candidate that evaluated mobile self-care literature and its implications on health policy, procedures and guidelines. Since publication, an updated literature search has uncovered additional mobile health app self-care trials, as critiqued in Chapter 6, along with the concept of blockchain data security. Collectively, Chapters 1 and 3 reflect the rapidly-expanding nature of this field. A key finding in Chapter 1 was the paucity of mobile self-care clinical trials and the potential for self-monitored health data to be integrated into healthcare services.

Chapter 2 reported semi-structured qualitative interviews with users of health apps, analysis of which provided insight into creating a health app usability framework. Chapter 2 delivered an understanding of consumer engagement with health apps, interactions with health professionals regarding self-monitoring, P2P sharing and self-management of data, all of which are relevant to the concept map presented on subsequent pages.

Chapter 3 presented a framework – collectively termed the ACDC – to evaluate eligible apps for their suitability for use in a clinical trial or endorsement by a health professional. The ACDC was grounded in qualitative findings in Chapter 2 and existing literature; its suitability and applicability to shortlist health apps is country-agnostic. Testing the model would be more realistically performed in Australia, since the concept map describes Australian systems, including the future $1 billion blockchain investment by the Australian government.[231] This incorporated a PRISMA-inspired flow diagram to screen and filter apps based on a given set of conditions. The ACDC was then used to rate and rank shortlisted apps. The framework was then validated twice, firstly with apps for asthma self-management, followed by apps for hypertension self-management, sourced from Apple's App Store® and Android's Google Play™. A key finding of Chapter 3 was the overwhelming proportion of health apps not meeting the ACDC criteria for clinical self-management of a chronic condition such as asthma or hypertension, and therefore the subsequent need for ongoing screening and evaluation of health apps in the broader arena.

7.2 Health App Ecosystem Concept Map

This section presents a concept map that amalgamates and synthesises the present thesis into a graphical artefact. The concept map comprises two core operational processes, namely, 'front-end' Consumer Engagement and Academic Evaluation of Apps (Part 1), and 'back-end' Data Utilisation, Transfer and Management (Part 2). These have been presented as separate graphics for clarity. The entire concept map presents a use case for three stakeholders: firstly, consumers, to appreciate how their proactive involvement in self-care and personal ownership of their health can influence clinical outcomes; secondly, clinicians, to understand their role in the self-care paradigm and to engage with consumers' self-documented data in electronic platforms; and thirdly, app developers, to understand the patient-clinician interaction in the design of user-friendly, functional interfaces.

Australia's National Digital Health Strategy involves a highly consultative process, providing secure, accessible and available digital health services to Australians.[232] Internal and external stakeholders such as physicians, pharmacists, researchers, network and infrastructure providers and consumers have been invited to provide iterative feedback on its development through a "national consultation" consisting of face-to-face forums.[233] The self-care concept map has the opportunity to be tested in accordance with the National Digital Health Strategy roadmap to test validity and reliability.[234]

The method used to create a concept map, depicting "organised knowledge", is outlined by Canas[235] and is further extended in the computing domain by Stoyanova.[236] Canas advocated the use of "cross-links" to represent relationships between various domains in a concept map. Individual domains, such as the Australian MHR, collectively form "knowledge domains", the overarching assessment or conceptual item being drawn. An example of cross-links (in Part 2) is the link between a consumer's smartphone (one domain) and the Australian MHR (another domain). These cross-links have been represented as lines or "connectors" in Microsoft Visio®. Stoyanova further supported the use of concept maps with verbal coding to "facilitate negotiation" of interrelated constructs and visual coding between participants to enhance "critical reflection" of the mobile self-care processes, as well as activating "mental imagery," through the use of symbols/pictures.[236] Stakeholders are individual actors, such as a developer or consumer with an interest in the domain, and can influence it or be influenced by it.

A conceptual framework has been developed as a "work in progress" in Maryland, USA, outlining the multi-faceted relationship between five "dimensions" such as the "Consume[r]/Individual," "Channel," "Information Sources," "Environment" and "Outcome."[237] This framework combines social research with health information systems to generate a working model applied to a health-related website. This framework closely shares the "Consume[r]/Individual" dimension with the concept map presented in this section (7.2), namely involving consumers' interactions with their health goals.[237] The remaining dimensions are unrelated to the concept map such as "Channel" and "Macro Environment" which focus on "health information seeking" factors such as "media channels" and "socio-economic/cultural environment," respectively.[237] No mention of adapting this framework to mobile technologies or health apps are presented. Contrary to the study's findings, not all consumers displayed "high acceptability" when seeking "health information."[79,235]

A previous Australian health IT manuscript presents a framework, covering system architecture of "digital health ecosystems, elaborating ontologies with the commonly-used Resource Description Framework Schema."[238] The self-care concept map; however, provides a functional, high-level overview of the front and back-end operational systems. The methodology presented here outlines the retrieval of data, harvesting through crawlers (or spiders) and verifying the schema's performance based on "relevant… and associated metadata."[238] This framework could render itself useful once the concept map includes functioning blockchain streams to send/retrieve data securely. Harvesting secure data in the blockchain; however, is not the scope of this thesis and an Application Programming Interface would be required for the crawler's algorithm to accurately harvest data.

Consideration of construct and face validity of the concept map among three researchers (the PhD candidate and two supervisors) ensured the map is representing what it is intended to represent,[239] namely, relevant and ideal interactions within the mobile self-care ecosystem.[200] Additionally, construct validity refined the concept map through an iterative process.[239] “Moderated interaction”, as outlined by Canas (2000), dictated the collaborative scenario used to construct the concept map, involving iterations until a “common group vision” is achieved.[235] As described in Section 7.4, this concept map depicts an ideal contemporary ecosystem.

7.3 Part 1: Consumer Engagement and Academic Evaluation of Apps

This sub-section presents the ‘front-end’ processes within the Health App Ecosystem Concept Map, as illustrated by Figure 13. ‘Back-end’ processes comprise Part 2 of the Concept Map, as described in Section 7.4. Four stakeholders are proposed: the app developer, consumer, academic researcher and clinician.

The core components of Part 1 of the concept map reflect the empirical research reported in this thesis. The first stage of the concept map involves a cycle (or “feedback loop”)[240] between the app developer, health consumer (user of the app) and academic researcher. This feedback loop ensures “active participation”[240] between stakeholders, in this case, involving the developer to reflect on findings. The developer’s role in this mobile self-care ecosystem is to consider and incorporate findings from trusted literature. This co-operation supports clinician confidence when selecting an app and aims to prevent ‘buggy’ apps.[241,242]

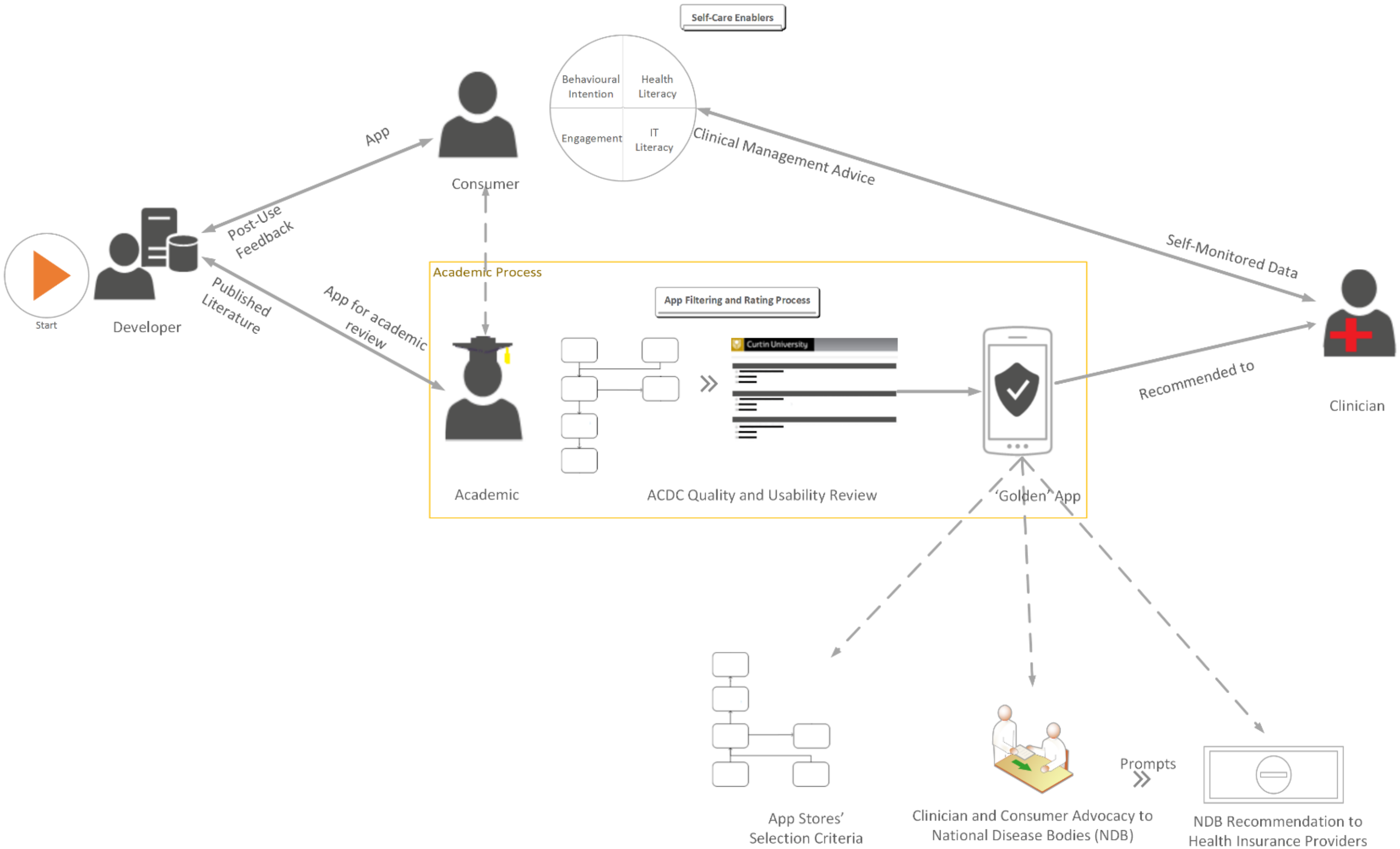


Figure 13: 'Front-end' Part 1: Consumer Engagement and Academic Evaluation of Apps

Domain 1: Self-Care by Health Consumers (Self-Care Enablers)

Domain 1 of the Health App Ecosystem Concept Map depicts consumers demonstrating certain attitudes and behaviours that facilitate self-care of their chronic condition. These attitudes and behaviours are partly represented by the "Behavioural Intention" component of the Behaviour Change Theory, as explored by Michie et al., 2011.[243] The remaining attitudes and behaviours are dependent on the consumer wanting to control their chronic condition, and in addition to Behavioural Intention, includes enablers cited in Anderson et al., 2016[65], namely, Engagement and Health/ICT Literacy. These enablers are illustrated above in Figure 13. Enablers represent facilitators of self-care, such as enablers for mobile devices of the evolving array of wearables.

Domain 2: App Filtering and Rating Processes

Occurring in parallel to consumer engagement are app evaluation processes. The academic researcher's role in evaluation of apps involves the initial screening and shortlisting of available health apps via a PRISMA-inspired flow diagram to identify apps for self-care based on parameters such as no cost to the consumer, in English and updated within the past 12 months.

After this initial screening, the remaining shortlisted apps are ranked using the ACDC instrument[110] using four themes, namely Engagement, Functionality, Ease of Use and Information Management. The 24 variables are scored, with subtotals for each criterion and a total for the app.

The 'golden' (top-scoring) app is subsequently identified for recommendation to clinicians, national disease bodies such as the National Asthma Council, Health Insurance Providers and selection criteria for app platforms such as Apple® and Google® when deciding which apps are accepted to respective app stores. The clinician, acts as a link between the consumer and the 'golden' app, for example, being aware of the app through academic literature, and recommending it to relevant patients.

Once the most suitable app is determined,[110] this 'golden' app is recommended for self-care of a chronic condition such as asthma or hypertension as part of a clinician-appointed self-care regimen. Health insurance providers, alerted to the app can then assess how their premiums can be adapted for clients who undertake appropriate self-care using reliable apps. Additionally, advocating this 'golden' app to a relevant national disease association, such as the National Asthma Council, can facilitate dissemination of this finding to members and the wider community alike. Moreover, building continuing evidence of such 'golden' apps can shine light on poorer-performing self-care apps; respective app stores can benefit from these findings and place more stringent pre-requisites for such clinically-oriented apps. This will result in more relevant and clinically-beneficial search results for consumers.

7.4 Part 2: Data Utilisation, Transfer and Management

This sub-section presents Part 2 of the Health App Ecosystem Concept Map, as illustrated in Figure 14.

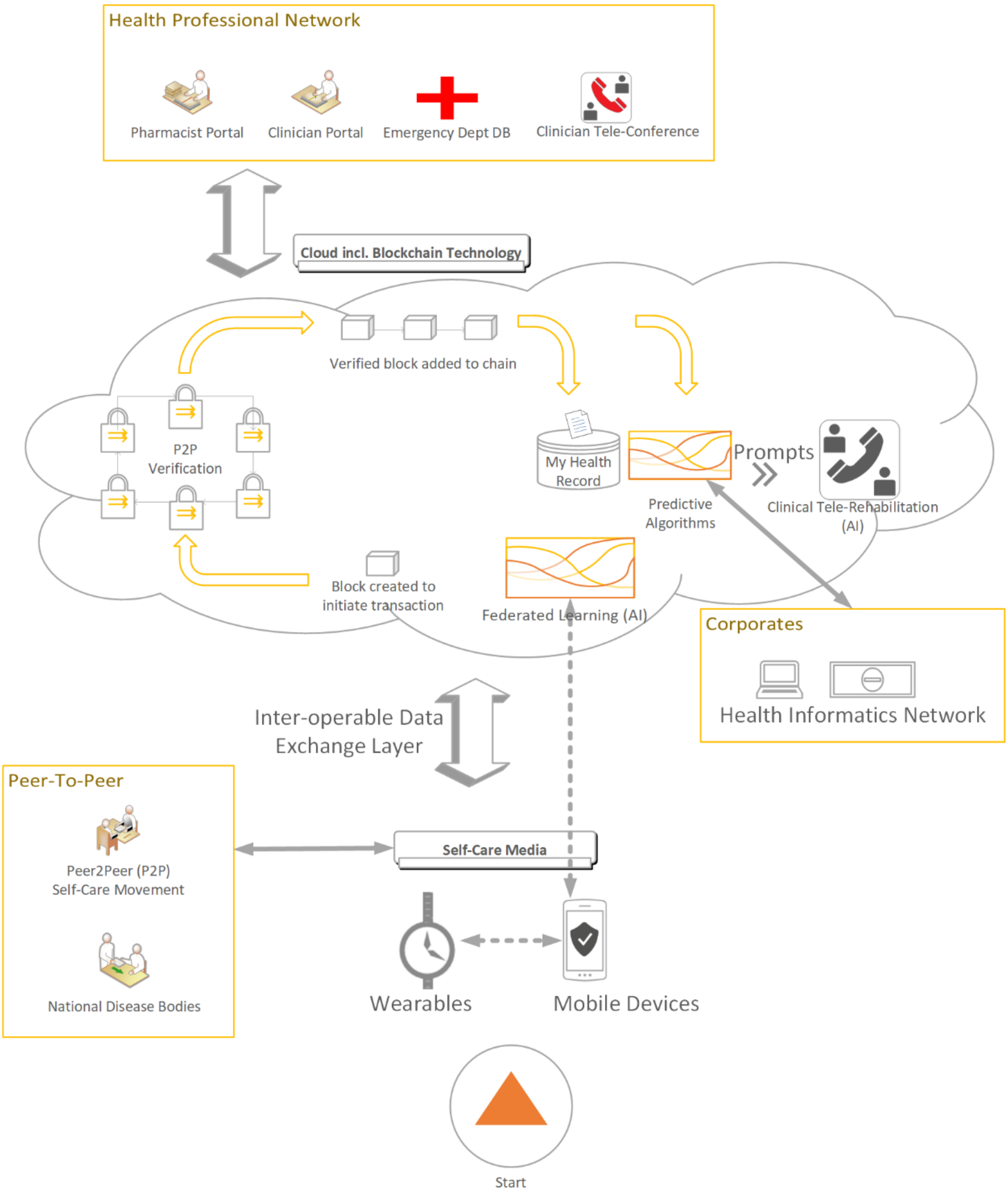


Figure 14: 'Back-end' Part 2: Data Utilisation, Transfer and Management

Domain 3: Self-Care Media

Part 2 of the concept map commences with "Domain 3: Self-Care Media" such as wearables and smartphones that capture and send clinical data to "Domain 4: Cloud, including Blockchain Technology."

Given the ubiquitous nature of mobile devices such as smartphones, tablets and wearables, adequate management of data from these self-care media is necessary to ensure accurate monitoring and reporting of one's condition. Developers should appreciate that the need for quality clinical apps for self-care management and app stores in the future warrants differentiation of such apps, providing consumers with informed choices when self-managing their chronic condition. Additionally, enablers for the Quantified Self movement include an adequate network of participants and active champions to continue the movement.[244]

Federated Learning, as described further in Domain 4,is a new concept that extends beyond Collaborative Machine Learning to include an individual's mobile device.[245,246] Federated Learning modules reside on a consumer's mobile device to instantaneously optimise efficiency and usability upon analysis of consumer activity without waiting for data sent back to servers for centralised aggregation. This implies faster inferences and a more personalised mobile health experience.[247] It is important to note not all (Artificial Intelligence) AI will use Federated Learning, as reflected in the concept map.

Domain 4: Cloud including Blockchain Technology

Proposed enablers for cloud integration include increased trust by consumers and (mobile-specific) data privacy laws to safeguard consumer data. Data storage services also require compliance with the *Health Insurance Portability and Accountability Act 1996*[248] for accountability in the case of privacy breaches and unpatched security vulnerabilities. An app's greater utilisation of raw consumer data will also assist as a 'training set' to teach an AI model, which is an algorithm residing in the cloud.

Additionally, it is essential for developers to ensure their app, which is fundamentally a "data capture interface", complies with blockchain infrastructure. For example, a health app uploading readings, clinical notes, pathology results or scans to the Australian MHR would require its back-end to comprise a "decentralised peer-to-peer" network (decentralised application or DApp[223]) to be considered blockchain-compliant. This is different from simply residing all data on one master server, which was the case with all apps with a user profile that were evaluated in the present study.

Each consumer has the opportunity to interact with their MHR[200] to take further control and management of their connected health. During this process, availability and interoperability of "Self-Care Media" (such as smartphones and wearables) with the MHR become apparent. It is important to note this concept map represents ideal processes in the future since wearables do not have the functionality to upload data to the MHR[200].

Domain 4 also involves the secure storage of medical records such as scans, blood tests, prescription medication approvals and referral notes using blockchain technology. Australian (and overseas) start-up companies are capitalising on blockchain, via platforms for medication management where the commonality between various general practitioners, specialists and pharmacists is the consumer. This focusses attention on revamping system architecture and connected eHealth systems to ensure data integrity and patient confidentiality is upheld and enforced. The future of hypertension apps, for example, is proposed here to involve AI models trained with test data, provided by the manufacturer/developer, generating a Bayesian Model to predict fluctuations in blood pressure based on the patient's other clinical and demographic data. The As-a-Service economy will also present opportunities to use subscription-based facilities, such as customised analytics or AI for pain management, on a needs basis.[249]

Enablers for the MHR[200] would further include inter-compatibility with other clinical systems across the self-care paradigm. Additionally, the Australian MHR has been placed in this category as it houses self-care data,[200] frequently updating data from smartphones and wearables.

Domain 5: Health Professional Network

As these medical data are being processed and stored, the "Health Professional Network" team is proposed to work co-operatively to ensure clinical outcomes are optimised by each healthcare professional accessing accurate, real-time data in the MHR for individual patients and through improved digital communication channels. For example, uptake and utilisation of the MHR by health consumers will provide health professionals and other service providers more clinical visibility into prescribed medications taken by each patient, across all prescribers. This provides efficiency for medication management. Similarly, Emergency Departments will welcome more specific data prior to patient arrival, with complete patient history and historical health app readings, aiding better informed clinical decision-making.[200]

Active stakeholders” in Section 7.5 refers to actors within the concept map including clinicians and consumers who are actively exchanging business processes such as prescribing medication, or uploading/retrieving medical records or test results.

7.5 Concept Map Summary

This concept map provides a futuristic account of how consumers can take charge of their health using wearables and other connected devices to upload data to their Australian MHR and communicate with their allied health/insurance providers, supported by blockchain.

There is capability to implement this mobile self-care concept map in primary care settings. The self-care ecosystem or concept map utilises published models (summarised in Table 43) and a logical framework to facilitate self-care for consumers with chronic conditions.

Table 43: Concept Map Referenced Literature

	Author	**Year**	**Framework Used**
Domain 1: Self-care enablers	Michie et al.	2011	Behaviour Change Wheel
Domain 2: App Filtering Process	Anderson et al.	2016	PRISMA-inspired flow diagram conditions and ACDC
Domain 3: Self-Care Media	Rifi et al. Mettler et al.	2017 2016	Blockchain P2P validation process
Domain 4: Cloud including Blockchain	N/A (emerging concepts; unpublished)		
Domain 5: Health Professional Network			

In the future, health insurance companies located within "Health Informatics" will enjoy more flexibility when aligning insurance premiums for each client based on metrics such as self-care efficacy and indicators of health literacy, where it is established that higher health literacy correlates with better health outcomes.[250] It is also important to acknowledge "Health Informatics" administered by health IT managers and health information managers who assist with operational and back-end processes.

Enablers for clinicians include decreased barriers to entry and easy-to-use portals, including task automation and efficient data entry. Analysis and integration into other healthcare systems such as pharmacies' dispensed medicines records is also an enabler. Similarly, additional education/training in accessing an eHealth record and entering data will decrease barriers to entry.

Moreover, the five domains present active stakeholders in a mobile health app ecosystem, exchanging regularly with the stakeholders such as consumers, clinicians and app developers. Reliance on collaborative care, engagement with technology, and need for data security all present realistic milestones for a productive and cutting-edge health app ecosystem.

8 CHAPTER 8: Discussion

8.1 Preface

This chapter provides a Discussion of the entire thesis findings. The updated literature review spanning January 2016 to January 2018 discovered a significantly greater proportion of mobile health app studies compared to the original published mapping review covering literature from January 2013 to January 2015.[82] The 2015-2016 gap was attended to during the creation of the ACDC, where literature updates ensured a scientifically-based usability checklist.[110] More significant investment for such health apps studies is being committed worldwide, with improvements to study design and parameters noted, such as the coupling of an educational component to the app offering, to educate consumers on self-care techniques with trial of an app.[74]

The main deficiencies in the literature warrant further and more conclusive RCTs with longer follow-up periods to validate use of mobile health apps for clinical self-care of chronic conditions. Emerging literature in this field presents proof-of-concept studies, for example, utilising a multi-faceted approach when implementing health apps, compared to traditional paper-based self-care techniques.[251]

Equity of service access is achieved through the mobile nature of health apps and increasing ownership of mobile devices.[252] This thesis focusses on mobile devices, although the use of web platforms is recognised.

8.2 Contribution of Mobile Self-Care to Health

Whether referring to literature from the 1970s[253] or present,[74,220,254] self-monitoring still presents clear potential to improve clinical outcomes for the patient.[255] Currently, the limited regulation of mobile health technologies in the marketplace allows insufficiently tested[241,242] self-monitoring devices to be launched, with potential consequences for health consumers to ill-advisedly change their self-care regimens or avoid medical consultation.

Health consumers are beginning to exhibit more control over app quality through the 2016 adaptation of the MARS[99], called uMARS by the same authors in Queensland, Australia, using fewer questions (n=20).[256] The uMARS empowers consumers by introducing more lay terms instead of subject-specific terminology, in addition to removing questions requiring "professional expertise," reducing a consumer's barrier to entry. Testing the uMARS against clinical management apps rather than eBook or informational apps, for example, is welcomed. It is agreed a "standardised method" for consumers to rate health app quality is required.[257] Both the MARS and uMARS used an "inductive approach"[257], whereas the ACDC utilised both inductive and deductive approaches to confirm the existing body of knowledge and complement it with a primary study using semi-structured interviews with consumer stakeholders.[65] Additionally, future studies can include a more representative sample of respondents completing the uMARS such as those found to be more prevalent for chronic conditions.

Support from published literature was a fundamental catalyst for the creation of the ACDC – to shortlist credible and functional health apps suitable for managing chronic conditions during a clinical trial and beyond. There are many instances of 'buggy' health apps.[241,242] Therefore, self-monitoring will benefit from guidelines to prevent errors or other incidents, as outlined by a number of authors.[258,259] The introduction of the Health Market Validation Program in Victoria in 2015,[260] and more recently, a web directory of health apps for Tasmanian General Practitioners (GPs)[261] in late 2017, signifies two Australian State Governments' recognition of the value of remote/home monitoring and health apps as part of a managed self-care regimen. No evaluation of these relatively recent initiatives has been published. Data on clinical outcomes, as well as economic aspects, user acceptability and engagement would be valuable.

As outlined by Brzan et al.,[199] counselling/education pages incorporated into apps provide useful guidance to consumers to learn correct techniques to generate data about their health condition, such as body position when taking systolic and diastolic pressure readings. During rating of hypertension apps (Chapter 5), the raters agreed 'how-to' videos and information relating to colour-coded traffic light markers provided useful insight into self-monitoring one's condition.

Similarly, connecting and sharing data with health professionals was also deemed to be essential in consistent monitoring of one's condition. In Australia, the bridge between consumers and allied health is becoming more usable through local state government initiatives such as the Tasmanian registry for health apps[261] intended for physicians to recommend apps to their patients, as outlined in Chapter 8.

Since self-care transfers responsibility to the consumer, the usability of technology for this purpose is imperative, as outlined in studies within the 2016-2018 timeframe.[74,199,218,220] Most self-care studies have acknowledged this, but have not conducted a thorough investigation of how usability can be optimised. The exception is a 2017 Australian asthma study.[220] Additionally, an earlier (2007) diabetes self-care study[262] involved blood glucose monitoring devices powered by mobile telephone batteries. This study applied qualitative and quantitative data collection, which is valuable to establish user satisfaction, and sourced a relevant range of participants. At the time of that study, smartphones were not available to the general public, hence the use of outdated (by today's standards) cellular firmware to obtain and transmit blood glucose data.

Updates to mobile self-care also require scalable technologies to suit changing technological environments and user preferences. The use of augmented reality and virtual assistants is becoming more commonplace, with their application in chronic disease management including medication reminders,[263,264] dental simulation apps[265] and patient vein locator apps.[266] Over time, the barrier to entry is reduced, and more active stimuli are available with which consumers can engage. Augmented reality is in its early stages, having been released on iOS version 11 on 19th September 2017[267], and was not evident in any apps evaluated in the present study, but has potential to assist with documentation of objective data for people with chronic conditions. Similarly, virtual assistants were not evident in shortlisted asthma or hypertension apps.

It is important to note that *acceptability* of the features of health apps is not necessarily aligned with *usability*. For example, a new gimmick or feature such as special offers or augmented reality[268] can entice consumers to download and 'accept' the app, but the usability of such features may not follow best-practice guidelines, and consequently, limit sustained app engagement.

Some apps rated in Chapter 5, such as "Heart Sure" by Michael Spilkin, have since been discontinued, as reported by App Advice.[189] This sends a timely reminder to adopt a lean approach when developing an app's potential, purpose and value proposition, in order to remain sustainable in the crowded health app market.

Moreover, it is important to note self-care directives are a cultural shift, requiring change-management practices for both consumers and developers[269,270] to prevent undesirable events[271] such as discontinuation of apps[189] and declined app engagement. Consumers and healthcare providers require assurance in their (or their patients') data management, including security and stability of data captured by the device or recorded by the user. Manufacturers of smart watches, for example, have failed to produce clear differentiation between devices other than aesthetic features. A quantum development would be achieved when the data collected from smart watches in Australia are linked to a healthcare provider's records, and the consumer's MHR, where patient medical data and summaries are secured 'in the cloud'.[272] This principle, currently futuristic, was proposed as Domain 4 in the concept map.

There are historical examples of healthcare providers acting upon paper-based[251] and electronic data[273] from consumers. However, few studies published recently mention the use and subsequent analytics[274] of patient-derived data, such as data accumulated by modern wearable technologies such as Fitbit®.[275-277] In the future, progression of such analytics depends on adoption of self-care principles and technologies by the population of interest. Whilst ample opportunity exists for consumers to use and share FitBit® data, this phenomenon is not as heavily cited in peer-reviewed literature, as in online communities, as identified when creating the ACDC. Moreover, there is a paucity of literature around how health professionals do, and might, use such data in their consultation with the consumer. Domain 5 of the concept map recognises the potential for cloud-based health data to be accessed by health professionals (with the consumer's permission) to enhance consumers' self-care.

Furthermore, self-education and liaison with health professionals as well as connecting records to an electronic health record, such as the Australian MHR,[200] have been stated as other factors in sustaining user engagement.[199] The former two features have been identified and recommended in the *PLOS ONE* paper by the author of this thesis.[65]

8.3 Implications for Policy and Practice

A peer-reviewed usability checklist, the ACDC, was synthesised based on interview findings and published literature. In October 2017, the New Zealand Ministry of Health acknowledged the creation of ACDC as useful in evaluating a health app.[193]

Since the WA Health Department's *Chronic Conditions Self-Management Strategic Framework 2011–2015*, the Department has published a *Health Networks Strategic Direction 2015-2020* that includes provisions for chronic conditions, that is, "Impact Area 5", to focus on prevention and early intervention of chronic conditions. A targeted Self-Management framework post 2011-2015 has not been released by the State Government. Potential directions of such a Self-Management framework could include clinical guidelines for clinicians to administer health apps as part of patients' self-care regimens.[261] Obvious implications would involve reputability of an app developer and adherence to clinical guidelines when developing the apps.

8.4 Strengths and Limitations of the Thesis

Using the HBM and the Health Information Technology Acceptance Model (HITAM), and guided by the post-positivism model of scientific inquiry, mixed methods research has been presented. In particular, the qualitative study confirmed that a range of users from WA were immersed in at least one app to manage their health. Semi-structured interviews uncovered key user preferences when monitoring health. One example was longitudinal diabetes readings mapped by time of the day, enabling overview of blood glucose fluctuations. Additionally, the use of mixed methods has complemented the quantitative study by "providing insights" from the qualitative study to inform design of the ACDC.[278] Additionally, mixed methods enable a more "complete picture," particularly when integrating data participants share through lived experience with health apps.[278]

This is the first time the HITAM and HBM have been used in a mobile health app study; for relevance these two theoretical models have been adapted to best suit the study design. Table 1: Interview Guide in Section 2.2 maps the core TAM components , that is, TAM – Subjective Norms, TAM – Ease of Use and TAM – Usefulness to the interview questions. Additionally, "Perceived Ease of Use" and "Perceived Usefulness" have been incorporated to the ACDC detailed in Section 3.2. For example, the Ease of Use construct in the checklist has been guided by literature and also the HITAM.[90] Similarly, during interview outlined in Section 2.2, questions surrounding “Attitude toward Use” and “Behavioral Intention to Use” were asked of respondents[65].

Additionally, the mixed-methods approach enables the study to benefit from qualitative findings from semi-structured interviews before creating the ACDC and deriving quantitative rating of apps.

Integration of different disciplines such as health (self-care), Information Technology with acknowledgement of commerce (marketing and availability of apps) and psychology (engagement, consumer behaviours) is a fundamental strength of this thesis. Additionally, synthesising this knowledge as a concept map presents additional value for future researchers and app developers. The concept map is unique in a number of ways, such as integrating blockchain developments into a mobile self-care model and acknowledging use of the Australian MHR, providing an interconnected mobile self-care ecosystem not published in the literature thus far.

This thesis presents a timely exploration of how health apps facilitate, and could in future further facilitate, self-care for consumers with chronic conditions. Hospitals, clinics, researchers, app developers and app stores are all potential beneficiaries of this thesis.

Certain elements were not in scope of this thesis, for example, incorporating public reviews and subjective star ratings for particular apps. Instead, the ACDC is presented as a structured academic process based on published literature. Future research could compare academic rating of apps with broader voluntary consumer reviews published in app stores.

Additionally, blockchain in health’s prevalence only emerged in the Australian scene towards the end of the present research. Due to its relevance, blockchain in health has been described in terms of the Australian MHR, but did not feature in the objectives of this thesis.

The ACDC did not consider relevance of apps to users of diverse cultural backgrounds; this would require a much more detailed checklist, rendering it impractical for larger-scale screening/ranking of apps. Additionally, reflecting on the “Salt Switch” study, population/user diversity relating to health technology literacy required to engage with apps is an area requiring further examination.[279] This level of scrutiny would be attained during implementation trials involving the academically-rated apps.

As a surrogate of health technology literacy, the panel of raters in the present study had self-declared high, moderate and developing levels of technological literacy. Future studies involving consumers incorporating a technology literature measure are envisaged.

Another limitation of this study pertains to the inclusion criteria of chronic conditions, namely, medical conditions for which objective data, such as peak flow readings and systolic/diastolic blood pressure readings, are key to self-care by consumers. Future studies could investigate chronic conditions associated with subjective data, such as menstrual disorders, depression/anxiety and chronic pain. The qualitative semi-structured interviews identified numerous participants who used apps for self-monitoring of these conditions.[65]

This study also excluded minors (users under 18 years of age), which can be another area of focus for future health app researchers.

9 CHAPTER 9: Conclusions

This chapter follows the Discussion commentary by summarising and concluding the entire thesis, and is presented as a Summary of Key Findings, reflecting on the objectives of this body of research, followed by an overall Conclusion.

9.1 Summary of Key Findings

Key findings for each main stage are provided below.

This thesis explored existing literature around mobile health app trials, guidelines, checklists and rating scales to consolidate the fast-moving body of knowledge. Additionally, consumer responses to health apps were investigated using questions backed by scholarly literature, which consequently informed the creation of the ACDC.

Shortlisting of chronic disease management apps was undertaken using a PRISMA-inspired flow diagram. Rating of shortlisted apps discovered a consistent paucity of evidence-based features in the identified apps, and therefore, limited functionality. This finding is consistent with a decrease in sustained app engagement, as uncovered during the qualitative stage. Additionally, many shortlisted apps were observed to have limited core features such as those to enable monitoring of clinical readings.

The adaption of blockchain technology from the financial sector to healthcare informed the literature update and also the mobile self-care concept map. The immutable nature of data retention and the proof-of-work processes such as mining facilitates techniques to ensure data integrity, presenting a renewed dimension of connected health.

This thesis aimed to enhance self-management for health consumers with chronic conditions via use of apps. The achievement of the specific objectives is reflected below:

Objective 1: Explore health consumers' interaction with health apps.

a. Semi-structured interviews with consumers with chronic conditions

Semi-structured interviews were conducted to establish consumer behaviour with health apps ranging from asthma and diabetes to celiac disease and sleep apnoea. This objective was achieved by interviewing health app users with diverse conditions to establish a wide range of responses. Findings revealed participants sought health apps that 'grew' with their condition or sustained their engagement throughout the course of their condition. For example, one participant in the study with chronic pain had only engaged with her pain management app during the first period of chronic pain and sporadically thereafter. Additionally, other participants admitted inconsistency with entering daily and timely clinical readings. The advent of patient-clinician communication was also of importance, with participants advocating the use of statistics to email their GP. Additionally, most participants valued in-app liaison with their health professional and the capacity to create a user profile.

The semi-structured interviews involved a range of consumers with a variety of chronic conditions from asthma and hypertension to coeliac disease and menstrual disorders. All consumers exhibited positive behaviour towards self-monitoring their health and provided useful remarks pertaining to user engagement and desired app features, which informed the creation of the app evaluation checklist.

b. Thematic analysis of qualitative interview data

QSR® NVivo™ Version 10 was used to manage transcribed interview data. Thematic analysis of participant responses resulted in the identification of four themes, namely Engagement, Functionality, Information Management and Ease of Use, consequently informing the next section.

2. **Objective 2: Evaluate available health apps for a particular chronic condition, via:**

a. Synthesis of a usability checklist

Semi-structured interviews were undertaken via reference to published literature. Interview transcripts were thematically analysed and collated with existing literature to create the ACDC, comprising four domains and 24 total questions. Applying the ACDC to two sub-studies, asthma and hypertension, coupled with peer review prior to publication in *JMIR Research Protocols*, ensured robustness.

The strength of combining two published models (TAM,[280] HITAM[90]) and a published checklist (MARS)[99] in a single study ensured breadth within the theoretical framework. As reported by a 2017 Australian asthma study,[220] consumer preferences and experiences are fundamental when designing health apps for sustained engagement. Therefore, post-positivism was the most suitable research paradigm and confirmed a strength to the thesis by recognising ever-changing user requirements and viewing “knowledge as conjectural”, as published in the *PLOS ONE* paper.[65]

The peer-reviewed ACDC originated from the qualitative study findings and recent health app usability literature. Weighting for each question was a crucial factor when deciding a three-point scale, since most questions included a ‘no’ response that required a value of ‘0’ to indicate absence of that characteristic.

b. Creation of a protocol to replicate findings

A protocol was devised, comprising dummy data to test shortlisted asthma and hypertension apps. This published protocol ensured other researchers can apply the same findings to other chronic conditions.

A PRISMA-inspired flow diagram was created to systematically filter available Apple and Android apps eligible for rating by the ACDC, and was found to be robust, yet adaptable, when shortlisting the multitude of available health apps.

3. **Objective 3: Evaluate and critically appraise health apps for a particular chronic condition, via:**

a. Critical appraisal of health apps for that chronic condition (asthma)

This section uncovered key elements of available asthma and hypertension apps also confirmed by a 2013 Canadian study by Goyal and Cafazzo[219] and reflected on in a 2016 Slovenian systematic review by Brzan et al.[199] The findings suggested a significant proportion of available health apps were not fit for clinical use or effective self-monitoring. This presents a concern for consumers in need of support for self-monitoring.

Appraisal of asthma apps revealed a small proportion of clinically-suitable apps. The closest app to approach the advocated 80% of the maximum score was “AsthmaMD” (47.0/72.0), 9.5 points lower than the highest hypertension app. “MyPeakFlow”, the lowest shortlisted asthma app, scored 10.5/72.

b. Validation of the protocol using another chronic condition (hypertension)

Only one (of 17) shortlisted clinical hypertension app originated from Australia. The app most closely approaching the advocated 80% of the maximum score was “Tactio Health” at (56.5/72.0). “Blood Pressure Monitor” (Timevy), the lowest shortlisted asthma app, scored 15.0/72.

Validating the protocol using another chronic condition requiring objective data input further strengthened the ACDC.

4. **Objective 4: Translate mHealth technology findings to industry via data synthesis from previous objectives, via:**

a. An updated literature review relevant to the current mobile self-care environment.

A literature review of evidence was published, and an update is presented in Section 6. This update to literature uncovered more studies committed to trialling health apps, along with blockchain’s emergence in the health domain.

b. Derivation of a mobile self-care concept map describing the mobile self-care eco-system

The mobile self-care concept map presents a novel combination of eHealth paradigms and published models, coupled with eCommerce in the form of marketing and health insurance. The advent of blockchain in health is also integrated throughout the concept map, facilitating future provisions of such technology.

9.2 Suggestions for Future Research

The significance of this work is far-reaching. The primary suggestion for future research is to create an evidence-based chronic disease management app using the ACDC as a best-practice framework, followed by consumer evaluation of the app to further validate the ACDC beyond the academic environment. Consumer evaluation could take place as a standalone study utilising the app, or within a clinical trial, whereby the app is one of a battery of measures. Inclusion criteria, an appropriate sample size, study duration and the monitoring protocol are considerations for the design of a consumer trial utilising a custom-designed app. The publication of such results will provide a significant update to the body of knowledge. Additionally, the concept map presented in Section 7.2 can be reinforced through consultation with stakeholder groups, providing insight into the perceived value through an "iterative and experiential" manner, advocating a "refined" and robust" model.[281] Additionally, for future research, the ability to test this concept map as a model with each of the stakeholder groups named in the map is of value.

Although marketing jargon exists for blockchain health solutions, implementing blockchain in a healthcare setting is likely to be extremely difficult, requiring high-level commitment from government, clinical facilities and technology providers. Despite the existence of privacy legislation, trial of its provisions in an Australian connected healthcare ecosystem is required. Suggestions include building a small-scale prototype, merely for medication management with dummy patient data, before approaching a hospital or primary care facility to validate blockchain transactions. Many multinational corporations such as IBM are actively investing in this space, with an Australian start-up (ScalaMed) presenting promise for future eHealth blockchain research, with their blockchain prescription management solution.

Profound potential exists for mobile self-care trials, with many global research groups allocating resources to this space. The advent of wearable technologies provides another angle for exploration of consumer experiences; the key for app developers is to ensure apps utilising data from wearables are validated through research and ideally endorsed by health bodies.

The countless 'prank' or entertainment health apps that remain on the market (and continue to be developed) serve no clinical purpose. Future research is suggested to enhance accountability for medical apps through more stringent review guidelines for mobile apps.[140]

There is growing acknowledgement from public hospitals in Australia to incorporate digital services such as health apps for patients upon discharge from hospitals. This inclusion of mobile apps requires a review of hospital business processes to ensure consumers are fully engaged with their prescribed apps, physicians can communicate with consumers through the app, infrastructure can support and secure this transaction and funding models are in place to ensure telehealth services can be funded and covered through a rebate of medical costs. This warrants an observational study of the acceptability and sustainability of such hospital-endorsed apps.

The concept that physicians are not 'tech savvy' and find it difficult to prescribe health apps to their patients should become redundant as new generations of 'digital native' physicians are trained. For example, with health app guidelines specifically created for physicians by the Royal College of Physicians in London,[204] and with new registrars and fellows involved with digital technologies in hospitals, there is potential for mixed-methods research into how health professionals locate, assess and recommend apps for their patients (consumers) in the form of a clinical trial.

Moreover, ongoing research should explore results from gold-standard RCTs using health apps validated through literature and preferably endorsed by a national health body. This way, more stakeholders provide their opinions on how self-care apps assist in managing chronic conditions.

9.3 Concluding Observations

The initial mapping review identified how Australian public policy provisions chronic conditions as a priority, but integration of mobile health app solutions was not addressed in Western Australia's Department of Health Strategic Plan. The abundance of health apps was noted; however, the clinical usefulness of these health apps to facilitate self-care for consumers with chronic conditions was unknown. A paucity of clinical trials for health apps catering for chronic conditions was evident, but the updated mapping review demonstrated greater investment of health app-related trials, backing key app features referenced by published literature. The advent of blockchain in health emerged during this period.

Self-care of chronic conditions using mobile apps is a growing area, with continued support from literature citing efficacy and translation into clinical outcomes, compared to traditional paper-based methods. The main challenge for the use of self-care apps is still the prevalence of apps without a strong evidence base, thus limiting the ability of practitioners in Australia to 'prescribe' apps as part of a self-care regimen.

Overall, this thesis presented the state of current health app trials through two mapping reviews, gained insight into health app user experiences via semi-structured interviews, created a peer-reviewed chronic disease checklist (the ACDC), applied the ACDC to a disease state (asthma) and validated results using a second disease state (hypertension). Thereafter, a concept map was synthesised, amalgamating all aspects of the thesis. Moreover, the future presents a promising outlook for self-care of chronic conditions using mobile health apps.

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I would be pleased to hear from any copyright owner who has been omitted or incorrectly acknowledged.

11 APPENDICES

Appendix 1: Journal Consent Forms

Correspondence from respective journals for copyright permission is provided below.

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C
Claire.Gibson@csiro.au
Fri 16/03, 12:46
Kevin Anderson

Reply all

Dear Kevin,

Thank you for your email.

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E claire.gibson@csiro.au

noreply@salesforce.com on behalf of Abby Hilling <plosone@plos.org>
Thu 15/03, 02:42
Kevin Anderson

Reply all

Dear Dr. Anderson,

Thank you for your patience. My colleague Amy has passed your case along to me for further handling.

Given PLOS ONE's CC BY copyright license, no written permission is needed to download, reuse, reprint, modify, distribute, and/or copy articles or images in PLOS journals. The only requirement when reprinting PLOS content is crediting the original creators (e.g., including the article's citation and/or the image credit). We are not able to sign any copyright forms because PLOS does not own the copyright permissions to our content.

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Sincerely,
Abby Hilling

PLOS | OPEN FOR DISCOVERY
Abby Hilling | Publications Assistant, PLOS ONE
1160 Battery Street, Suite 225, San Francisco, CA 94111
ahilling@plos.org

Case Number: 05674726

Reply all | Delete Junk | ...

[JMIR Publications] Re: Inserting my JMIR Publication to my PhD

Editorial Director (Production Support) <prod-support@jmir.org>
Yesterday, 04:06
Kevin Anderson

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To help protect your privacy, some content in this message has been blocked. To re-enable the blocked features, click here.

To always show content from this sender, click here.

##- Please type your reply above this line -##

Your request (5408) has been updated. To add additional comments, reply to this email.

Editorial **Editorial Director** (JMIR Publications)
Mar 22, 16:06 EDT

Dear Kevin Anderson,
Thanks for your inquiry.
We cannot give you permission as we don't own the copyright - you do.
An article covering your question can be found in our Help Center / Knowledge Base (KB).
Please see below for the suggested KB article(s).

For future reference, we recommend searching the Knowledge Base at https://jmir.zendesk.com/hc/en-us first. Please let us know if the articles in the Help Center do not solve your problem.

Regards,

Your JMIR Support Team.

Suggested Knowledge Base Article(s):
Can you give me permission to publish my article as part of my thesis or book?

Appendix 2: Participant Information Statement

PARTICIPANT INFORMATION STATEMENT

HREC Project Number:	*RDHS-102-15*
Project Title:	**Self-Care: Exploring Health Consumers' Interaction with Mobile Health Applications**
Principal Investigator:	A/Prof Lynne Emmerton School of Pharmacy
Student researcher:	Mr Kevin Anderson
Version Number:	0.1
Version Date:	30/03/2015

What is the project about?
Australians are living longer, but this means more pressure on the health system, so we all need to be able to look after ourselves to some extent. Many people use health apps to help manage their health and fitness. This research is looking at how people use health apps, and their good, bad and so-so experiences with health apps.

Who is doing the research?
- The project is being conducted by Mr Kevin Anderson, Prof Lynne Emmerton and Dr Oksana Burford.
- This research is part of a PhD in Pharmacy at Curtin University.
- This project is internally funded through Curtin University.
- There will be no costs to you.

Why are you being asked to take part and what will you have to do?
- We are looking for users of health apps who are over 18 years old.
- Your participation will involve a one-on-one interview about how you use the app, what you like/dislike about the app, and a few simple questions about yourself.
- The interview will take place at a mutually convenient location.
- The interview is expected to last 20 minutes.
- You will be reimbursed with a $20 Coles gift card for your time.
- There will be no cost to you for taking part in this research.
- If you agree, the interviewer will make a digital audio recording so as to concentrate on what you have to say and not be distracted with taking a lot of notes. After the interview, the researcher will make a full written copy of the recording.
- No access to medical records is required.

Are there any benefits to being in the research project?

- There may be no direct benefit to you from participating in this research.
- Sometimes, people appreciate the opportunity to discuss their opinions.
- We hope the results of this research will allow us to:
  - Identify ideal features of health apps
  - Set up another study to measure whether 'good' apps can help improve people's health.

Are there any risks, side-effects, discomforts or inconveniences from being in the research?

- There are no foreseeable risks from this research project.
  We have been careful to make sure that the questions in the survey do not cause you any distress. However, if you feel anxious about any of the questions, you do not need to answer them. If the questions cause any concerns or upset you, we can refer you to a counsellor.
- Apart from giving up tour time, we do not expect that there will be any risks or inconveniences associated with taking part in this study.

Who will have access to your information?

- The information collected in this research will be re-identifiable. Even though you will be asked to give your name and signature on the Consent Form, this will be kept separate from the interview. This means it is possible to match the code number back to the consent form. Any information we collect and use during this research will be treated as confidential. The following people will have access to the information we collect in this research: the research team and the Curtin University Ethics Committee
- Even though you will be asked to give your name and signature on the Consent Form, this will be kept separate from the interview, and information you provide will only be reported as a code number.
- Electronic data will be password-protected and paper forms will be in locked storage.
  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. You will not be identified in any results that are published or presented.

Will we tell you the results of the research?

- The results will be available through publications as group results, not individual results.
- However, if you are particularly interested in receiving a summary of this research, please let the interviewer know.

Do you 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 any thing that needs to be done so you can withdraw safely. If you chose not to take part or start and then stop the study, it will not affect your relationship with the University, staff or colleagues. If you choose to leave the study, we will use any information collected unless you tell us not to.

What happens next and who can you contact about the research?

Mr Kevin Anderson
PhD Candidate (researcher)
Kevin.Anderson2@postgrad.curtin.edu.au

Prof Lynne Emmerton
Professor, Pharmacy (supervisor)
Lynne.Emmerton@curtin.edu.au
9266 7352

If you decide to take part in this research, we will ask you to sign the consent form. By signing, it is telling us that you understand what you have read and what has been discussed. Signing the consent 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 to keep.

All research in Australia involving humans is reviewed by an independent group of people called a Human Research Ethics Committee (HREC). The ethical aspects of this research project have been approved by the Curtin University HREC. This project will be carried out according to the National Statement on Ethical Conduct in Human Research (2007). If you have any concerns and/or complaints about the project, the way it is being conducted or your rights as a research participant, and would like to speak to someone independent of the project, please contact: The Curtin University Ethics Committee by telephoning 08 9266 2784 or by emailing hrec@curtin.edu.au.

Appendix 3: Participant Consent Form

HREC Project Number:	*RDHS-102-15*
Project Title:	**Self-Care: Exploring Health Consumers' Interaction with Mobile Health Applications**
Principal Investigator:	Prof Lynne Emmerton School of Pharmacy
Student researcher:	Mr Kevin Anderson
Version Number:	0.1
Version Date:	18/03/2015

- I have read the information statement version listed above 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 March 2014.
- I understand I will receive a copy of this Information Statement and Consent Form.

Participant Name	
Participant Signature	
Date	

Declaration by researcher: I have supplied an Information Letter and Consent Form to the participant who has signed above, and believe that they understand the purpose, extent and possible risks of their involvement in this project.

Researcher Name	
Researcher Signature	
Date	

Appendix 4: Apps used by Participants

App Name	Operating System	Used by Participant Number	Number of Participants
"Blood Pressure Monitor - Family Lite"	iOS	P6	1
"BUPA Food Switch"	Android	P11	1
"Calorie King"	iOS	P2, P20	2
"Cardiio"	iOS	P13	1
"Diabetes Australia"	iOS	P2, P17	2
"Diabetes in Check"	iOS	P2	1
"Easy Diet Diary"	iOS	P3	1
"Every Trail"	iOS	P12	1
"Fitbit"	iOS Android (P9, P11, P18)	P2, P3, P9, P10, P11, P15, P18	7
"FitStar"	iOS	P15	1
"Global Corporate Challenge"	iOS Android (18)	P3, P18	2
"Google Fit"	Android	P9, P14	2
"Health Kit"	iOS	P7, P16	2
"iManage Migrane"	iOS	P8	1
"Lorna Jane"	iOS	P2, P3	2
"Map My Run"	iOS	P21	1
"Michelle Bridges 12 Week Challenge"	iOS	P2	1

(fitness app)			
"Migrane Diary"	iOS	P5	1
"Misfit"	Android	P8	1
"My Calendar"	iOS	P6	1
"MyFitnessPal"	iOS Android (P22)	P2, P9, P15, P17, P19, P21, P22	7
"Nike+ Running"	Android iOS (P21)	P14, P18, P21	3
"Noom Coach"	Android	P1	1
"Pact"	Android	P9	1
"Period Calendar"	Android	P1	1
"Period Tracker Lite"	iOS	P4	1
"Pillow"	iOS	P13	1
"Polar Beat"	iOS	P15	1
"ProPain Tracker"	iOS	P8	1
"Run Keeper"	iOS Android (P9,18)	P2, P3, P9, P16, P18	5
"Sleep as Android"	Android	P14	1
"Sleep Pillow"	iOS	P6	1
"Sony Lifelog"	Android	P9	1
"Strava"	iOS	P12	1
"Weight Watchers Mobile"	iOS	P2	1
"23&Me" (app component)	iOS	P16	1

“iBGStar”	iOS	P17	1
“Glucose Buddy”	iOS	P17	1
“Diabetes Australia App”	iOS	P17	1
“Endomondo”	Android	P18	1
“Instant Heart Rate“	iOS	P20	1
“Interval Timer“	iOS	P21	1
“Sleep Cycle“	iOS	P21	1
“Period Diary“	Android	P22	1
“Yoga Download“	Android	P22	1
“Beyond The Whiteboard“	Android	P22	1
Standalone Peripheral Device			
FreeStyle InsuLinx“	Bluetooth®	P20	1
“23&Me“	Saliva analysis kit	P16	1
“Apple Watch“ (biofeedback)	Bluetooth® (iOS)	P7	1
“Withings Smart Body Analyzer“	Digital weighing scales (iOS, via Bluetooth®)	P16	1
“Wild Divine“	Bluetooth® bio-feedback (iOS)	P13	1

Appendix 5: Deconstructed Interview Themes to Form ACDC Constructs

- Ease of Use
  - Automation
  - Convenience
  - Fun Factor
  - Health Literacy
  - TAM - Ease of Use
- Engagement
  - Competition
  - Effectiveness
  - Embarrassment
  - Frequency
  - Guilt
  - Health Management
  - Loyalty
  - MARS - Engagement
  - Motivation
  - Planning
  - Recommendation
  - Regularity of Life
  - Self-Awareness _ Self-conciousness
  - Self-Reflection
- Functionality
  - Annoying
  - Connect to services e.g. insurance, doctors
  - Functional Usefulness
  - Future Information Features
  - Graphical Output
  - Initial User Profile Setup
  - Layout
  - Navigation
  - Peripheral Device
  - Poor Guidance
  - Sensitiveness
  - Tactile, sound, sight feedback
  - TAM - Usefulness
  - Unhealthy Range Warning
- Information
  - Accuracy
  - Data Security (Cloud)
  - Performance Power
  - Privacy (value-added services)
  - Quality of Information - Gov body or equiv
  - Quantity of Information
  - Reliability _ bugs
  - Statistics
  - Too Much Information

Appendix 6: ACDC (*JMIR* Appendix)

Multimedia Appendix 1

App Chronic Disease Checklist v1.0

Q1.1 What is your name?
- ❍ Rater 1
- ❍ Rater 2
- ❍ Rater 3
- ❍ Group Consensus
- ❍ Dummy Values for Protocol

Q1.2 What is the name of the app you're rating?

____

Q1.3 On which platform are you using this app?
- ❍ iOS
- ❍ Android

Q1.4 Which chronic condition does this app address?
- ❍ Asthma
- ❍ Hypertension
- ❍ Mental Health
- ❍ Other

ENGAGEMENT

Q2.1 Gamification: Does the app apply gaming principles (such as digital rewards, prizes, leaderboards, badges, aggregated readings or competitions) to engage users?

- No, or not apparent initially (for new users)
- Yes - one/some
- Yes - numerous

Q2.2 Customisation: Does the app allow customisation of features (e.g. sound, content, notifications etc.)?

- No, app does not allow any customisation
- Yes - but limited, e.g. requires resetting each time
- Yes - allows comprehensive customisation

Q2.3 Interactivity: Does the app enable users to enter free-text reflections alongside their clinical data?

- No, or not apparently
- Yes - but limited
- Yes - ample free-text options

Q2.4 Engagement through Use of Plug-ins: Can the app connect with a peripheral device (e.g. via Bluetooth)?

- No, or not apparently
- Yes - but not obvious, or not a key feature of the app
- Yes - obvious and a key feature of the app

Q2.5 Self-Awareness: Does the app encourage the user to develop self-reflection and/or increased self-awareness of the chronic condition?

- No, or not apparently
- Yes - but to a limited extent
- Yes - comprehensively

Q2.6 Positive Behavior Change: Does the app encourage positive self-care practices (lifestyle or behavioural action), e.g. using reminders, tips or social influences?

- No, or not apparently
- Yes - but to a limited extent
- Yes - comprehensively

FUNCTIONALITY

Q3.1 Health Warnings: Does the app provide warnings about, or highlight, out-of-range readings?

- ❍ No warnings or highlights provided
- ❍ Yes, warnings/highlights provided, but with no guidance/support
- ❍ Yes, warnings/highlights provided, with guidance/support

Q3.2 Feedback: Does the app provide tactile, visual and/or sound feedback?

- ❍ No tactile, visual and/or sound feedback provided
- ❍ Limited tactile, visual and/or sound feedback provided
- ❍ Comprehensive tactile, visual and/or sound feedback, with additional controls/features (e.g. on/off, calendar integration)

Q3.3 Structural Navigation: Does the app facilitate sequential/appropriate navigation?

- ❍ No, or not apparently
- ❍ Yes, but with some deficiencies in functionality/links
- ❍ Yes, seamless structural navigation

Q3.4 Intuitive Design: Is the app designed for intuitive use (e.g. identifiable data input fields, intuitive symbols, generous touch areas)?

- ❍ No, or not apparently
- ❍ Yes, but to a limited extent
- ❍ Yes - comprehensively

Q3.5 Connection to Services: Does the app have capacity to send or connect data to another service (e.g. Apple Health)?

- ❍ No, or not apparently
- ❍ Yes - but to a limited extent (e.g. email data to self only)
- ❍ Yes - comprehensively

Q3.6 Performance Power: How fast do the app features (functions) and components (buttons/menus) work?

- ❍ Slow or inefficient, times out or crashes
- ❍ Reasonably efficient
- ❍ Very efficient, additional functionality (e.g. ‘loading time’ indicator)

EASE OF USE

Q4.1 Holistic Usability: Can all relevant self-management tasks be easily completed in this single app?
- ❍ No - not easily; requires another app to record certain/limited instructions
- ❍ Yes - but still requires another app
- ❍ Yes - all readings can be recorded on this app

Q4.2 Automation: Does the app facilitate automation of tasks, e.g. with pre-populated fields, suggestions based on inputs, management of medical appointments, automated customer service?
- ❍ No, or not evidently
- ❍ Yes - limited automation evident
- ❍ Yes - comprehensive automation evident

Q4.3 Medical and Technological Jargon: Is the app free from confusing (medical and/or technology) jargon?
- ❍ No - jargon evident
- ❍ Yes - mostly consumer-friendly terminology
- ❍ Yes - consumer-friendly terminology throughout

Q4.4 User Profile Setup: Does the app provide easy setup of a user profile, e.g. option to login via social media account?
- ❍ No, app operates without user profile or registration upon download
- ❍ Yes - limited user profile setup present
- ❍ Yes - easy, guided, comprehensive profile; social media login provided

Q4.5 Offline mode: Does the app operate in offline mode?
- ❍ No - app does not operate in offline mode
- ❍ Yes - but limited offline functionality
- ❍ Yes - comprehensive features available in offline mode; syncs when back online

Q4.6 Reminders: Does the app enable users to set reminders?
- ❍ No, or not apparently
- ❍ Yes - basic reminders can be set
- ❍ Yes - advanced reminders can be set, e.g. synced with external calendar, integrated with SMS

INFORMATION MANAGEMENT

Q5.1 Statistics: Does the app enable analysis of clinical data (e.g. produces statistics, graphs)?
- ❍ No, or not apparently
- ❍ Yes - but limited analysis
- ❍ Yes - comprehensive statistics available; can be exported for further analysis

Q5.2 Privacy and data security: Does the app allow secure data input and export (e.g. password management, encryption, privacy statement, cloud backup)?
- ❍ No, or not apparently
- ❍ Yes - basic security/privacy features
- ❍ Yes - comprehensive security/privacy features

Q5.3 Quality and Accurate Information: Does the app accept and display correct, relevant information regarding the chronic condition?
- ❍ No, or not apparently
- ❍ Yes - but with some limitations, e.g. does not detect out-of-range values entered
- ❍ Yes - comprehensive controls over data entry; entered data consistent with displayed outputs

Q5.4 Quantity of information: Is health information offered by the app concise but still comprehensive?
- ❍ No, too minimal or overwhelming
- ❍ Yes - but gaps or unnecessary detail present
- ❍ Yes - offers concise but comprehensive information

Q5.5 Visual information: Is visual explanation of concepts – through charts, graphs, images, videos etc – clear, logical and correct?
- ❍ No - unclear, illogical or incorrect visual information
- ❍ Yes - but sometimes unclear, illogical or incorrect
- ❍ Yes - clear, logical and correct

Q5.6 Credibility: Is the app developer/producer credible, e.g. uses a recognised logo or cites research?
- ❍ No, or not apparently, e.g. no credentials displayed
- ❍ Yes - credentials displayed
- ❍ Yes - comprehensive credentials displayed; cites research

Appendix 7: ACDC Instructions for Raters (*JMIR* Appendix)

Step	Preparation tasks	Required Kit	ACDC Reference
1	Assemble the list of apps retained by the PRISMA flow diagram Use www.random.org to select which apps all raters are to assess in the same order (thus minimising the risk of updates influencing scores)	Retained app names www.random.org	
2	Install each clinical management app from respective app store	Mobile device with internet connection, completed PRISMA flow diagram to determine which app	
3	Follow displayed instructions for new users such as establishing or registering a user profile	Smartphone with internet connection	Ease of Use: User Profile Setup
4	Use dummy profile data in Figure 2 as created by own lead investigator and insert clinical values	Smartphone with internet connection, dummy profile data (Figure 2)	
5	Spend five minutes familiarizing yourself with the app Close the app completely then re-open it	Smartphone with internet connection	
	Observations during Clinical Data Entry		
	When performing clinical data entry below:		
6	Note the visual appeal of the user interface	Refer to Step 3	Functionality: Graphics and Visual Appeal
7	Identify sequential, structural navigation	Refer to Step 3	Functionality: Structural Navigation
8	Recall responsiveness of app features and components	Refer to Step 3	Functionality: Performance Power
9	Observe medical or technical jargon	Refer to Step 3	Ease of Use: Medical and Technical Jargon
	Clinical data entry		
10	Enter clinical measures such as peak flow readings for one week using healthy range values as per Figure 3	Lead investigator to input dummy profile and set of readings similar to Figure 2 + 3	Functionality: Intuitive Design Information Management: Quality and Accurate Information
11	Enter clinical measures (as appropriate) for one week using uncontrolled and unhealthy range values and some missing values (Figure 3 is a guide)	As above	Functionality: Intuitive Design Information

			Management: Quality and Accurate Information
App functionality permitting, complete the following tasks			
12	Note any health warnings provided when inputting unhealthy range values	Refer to Step 3	Functionality: Health Warnings
13	Respond to feedback provided by app such as personal strengths or limitations	Refer to Step 3	Engagement: Self-Awareness
14	View graphical representation of inputted data in graph and numerical form	Refer to Step 3	Information Management: Visual Information
15	Add notes to data entries e.g. high blood pressure due to weightlifting class	Refer to Step 3	Engagement: Interactivity
16	Email the data or outputs to yourself and another rater Ensure emailed data (e.g. .xls, .csv) is readable without significant formatting required	Smartphone mail configuration	Functionality: Connection to Services
17	Access points/rewards system – have your readings accrued any points?	Refer to Step 3	Engagement: Gamification
18	Add goals (lead investigator should devise appropriate goal(s) as part of the dummy readings to be entered)	Refer to Step 3	Engagement: Self-Awareness + Positive Behaviour Change
19	Create in-app calendar entry	Smartphone calendar sync	Functionality: Feedback
20	Initiate daily medication reminder 06:30	Refer to Step 3	Ease of Use: Reminders
21	Attempt to interact with other nominated users or support services (e.g. a helpline)	Refer to Step 3	Functionality: Connection to Services
22	Attempt to change settings (e.g. fonts, colours, notifications)	Refer to Step 3	Engagement: Customisation
23	Navigate to statistics screen and produce multiple views of data, e.g. weekly and/or monthly	Refer to Step 3	Information Management: Statistics
24	Locate user prompts regarding lifestyle tips or behavioral advice based on user input, e.g. ramifications of medication overuse	Refer to Step 3	Engagement: Positive Behaviour Change
25	Locate option to connect app to peripheral device, e.g. Bluetooth monitor	Peripheral device and refer to Step 3	Engagement: Use of Plug-ins
26	Is another health app required to supplement features not available in this app?	Refer to Step 3	Ease of Use: Holistic Usability
27	Identify automated app features such as	Refer to Step 3	Ease of Use:

	pre-populated fields and appointment management		Automation
28	Identify password management option, privacy statement, cloud backup and data encryption	Refer to Step 3	Information Management: Privacy and Data Security
29	Observe extent of information provided for mobile experience	Refer to Step 3	Information Management: Quantity of Information
30	Recognize credible source of app, e.g. government lab logo, cites published research	Smartphone without internet connection	Information Management: Credibility
31	Turn off internet connection and test clinical data input and output displays	Smartphone without internet connection	Ease of Use: Offline Mode

Appendix 8: Peak Flow Chart Consent Form

Re: Permission to Use Graphic For Research

Helen Reddel <helen.reddel@sydney.edu.au>

Tue 31/05/2016 17:49

To: Kevin Anderson <kevin.anderson2@postgrad.curtin.edu.au>;

Dear Kevin

Thanks for your email, and for your interest in the peak flow chart. There is no problem with your using the it in your research; I would appreciate if you could acknowledge the source.

You might be interested to read a couple of papers relevant to the design of the chart:
Reddel HK, Vincent SD, Civitico J. The need for standardisation of peak flow charts. Thorax 2005; 60: 164-7.
Jansen J, McCaffery KJ, Hayen A, Ma D, Reddel HK. Impact of graphic format on perception of change in biological data: implications for health monitoring in conditions such as asthma. Prim Care Respir J 2012; 21: 94-100.

In the image in your email, I noticed that there is a problem with the numbers after the first and second weeks; I will correct the pdf and send you a fresh copy.

Best wishes for your research,

Helen

Helen Reddel, MBBS PhD FRACP
Clinical Associate Professor, Central Clinical School, University of Sydney
Research Leader, Clinical Management Group, Woolcock Institute of Medical Research
Honorary Visiting Medical Officer, Dept of Respiratory Medicine, Royal Prince Alfred Hospital
Chair, Global Initiative for Asthma (GINA) Science Committee