Internet of Things enabled sedentary behaviour change in office workers: development and feasibility of a novel intervention (*WorkMyWay*)

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Abstract

Sedentary behaviour (SB) without breaks is associated with adverse health outcomes. The prevalence of prolonged sitting at work among office workers makes a case for SB interventions to target this setting and population. Everyday mundane objects augmented with microelectronics and ubiquitous computing represent a novel mode of delivery for behaviour change interventions enabled by the Internet of Things (IoT). However, there is insufficient research to guide the design of interventions delivered with smart objects. This research addresses this gap by developing *WorkMyWay*, a workplace SB intervention delivered with IoT-enabled office objects (e.g. smart water bottles and cups), and evaluating its feasibility and acceptability in an 8-week "in-the-wild" study. This thesis made 4 contributions across the disciplines of behavioural medicine and human-computer interactions (HCI).

The first contribution is the development of the *WorkMyWay* intervention, which is informed by findings from a systematic scoping review of prior research in this field (Chapter 3), a diary-probed interview study with 20 office workers (Chapter 4), and a series of technology audit, prototyping, human-centred design, and requirement engineering processes (Chapter 5). Findings from the feasibility study (Chapter 6) suggest that despite technical issues with the data connection, participants perceive high value of *WorkMyWay* in changing their SB. The intervention is potentially implementable in office-based workplaces, as long as connectivity issues are fixed. Recommendations are made on improvements and a series of future studies in accordance with the Medical Research Council's guidance on complex intervention development and evaluation.

Second, this thesis deepens the theoretical understanding of SB change, by following the Behaviour Change Wheel framework (including the COM-B model, theoretical domain framework, and taxonomies of Behaviour Change Techniques (BCT)) throughout intervention design and evaluation. The intervention contents are specified using the BCT taxonomies (Chapter 5) and informed by the first published COM-B analysis of office worker's prolonged sitting behaviour at work (Chapter 4). This allows the feasibility study (Chapter 6) to contribute to theory development by matching the interview questions and psychological measures (e.g. strength of habit) with the BCTs (e.g. action planning, prompts and cues) and associated theoretical underpinnings (e.g. goal accessibility). It also

allows implementation issues to be considered in light of how well those theories and theory-informed BCTs can work in real-life settings.

Third, this thesis makes a methodological contribution by documenting an interdisciplinary approach to develop a digital behaviour change intervention and a model for applying and developing theories of behaviour change in the wild. This helps address the challenge identified in Chapter 3, by bridging the gap between HCI and behavioural medicine, and catalyse the process of feeding technological innovations downstream to health practice and intervention research.

Fourth, this research contributes to the HCI literature by proposing a 2×2 matrix framework to guide the design of technology for sustainable behaviour change. On one hand, the framework unifies some of the existing visions and concepts about ubiquitous computing and applies them to the context of behaviour change, by considering the type of cognitive process (automatic versus reflective, based on the dual process model) through which a persuasive design influences the behaviour. For another, the framework considers the required dosage of their technology intervention to maintain the behaviour, or the distribution of changes between the physical world and the human cognition.

Author contributions to thesis

The research theme of 'Internet of Things (IoT)' was suggested by the Horizon Centre for Doctoral Training (CDT) and the industry partner, Unilever UK. Ltd., who jointly funded this PhD research. The idea of applying IoT to the area of behaviour change with the example of promoting regular micro-break behaviours in office work was proposed and developed by the author during the first year of doctoral training, with feedback from a number of academics associated with the Horizon CDT, in particular from Prof. Steve Benford, Dr. Holly Blake, who later became the authors' PhD supervisors.

All the research in the thesis was designed by author, with guidance and oversight from her two supervisors. The author was responsible for producing protocols, acquiring ethical approvals for all studies in the thesis and the associated tasks of data collection, analysis and interpretation. Help was received from Dr. Blake in participant recruitment (Chapter 4 & 6). 4 Medical School students assisted in interview data transcription (Chapter 4). Anna Roberts from University College London Centre for Behaviour Change reviewed the Theoretical Domain Framework coding (Chapter 4) and discussed disagreement with the author. Roma Patel from the Horizon CDT assisted in the design and delivery of the stakeholder design workshop (Chapter 5) as well as in securing the Balance Network funding as a co-investigator, with administrative support from Felicia Black, the Digital Economy network manager.

The author designed both the *WorkMyWay* intervention and the IoT delivery system, including the interaction flow, information architecture, user interface and activity classification algorithm. Dominic Price, a developer based at the Horizon Digital Economy Institute volunteered his time to implement and maintain the Android Application that actuated the IoT system and provided automated feedback to participants over the study period. The author was responsible for writing the requirement specification document and usability testing for the Android development.

Publications and presentations

Huang Y., Benford S., Blake H. (2019). Digital Interventions to reduce sedentary behaviours in office workers: a scoping review. *Journal of Medical Internet Research* http://dx.doi.org/10.2196/11079

Huang, Y., Benford, S., Hendrickx, H., Treloar, R., and Blake, H. (2017). Office Workers' Perceived Barriers and Facilitators to Taking Regular Micro-breaks at Work: A Diary-Probed Interview Study. *PERSUASIVE '17.* Lecture Notes in Computer Science (LNCS). 10171. Springer, Cham. 149-161

Huang Y. (2016). How to Design Internet of Things to Encourage Office Workers to Take More Regular Micro-Breaks In: *Proceedings of the European Conference on Cognitive Ergonomics*. 32:1-32:3

Skatova A., Bedwell B., Shipp V., **Huang Y.**, Young A., Rodden T. and Bertenshaw E. (2016). The Role of ICT in Office Work Breaks In: *Proceedings of the 2016 Conference on Human Factors in Computing Systems,* Pages 3049-3060

Huang Y., Skatova A., Bedwell B., Rodden T., Shipp V., Bertenshaw E. 2015. Designing for Human Sustainability: The Role of Self-Reflection In: *Proceedings of the 17th International Conference on Human-Computer Interaction with Mobile Devices and Services Adjunct - MobileHCI '15*. 1042-1045

Design and development of *WorkMyWay*, a work break intervention delivered with Internet of Things (IoT), Oral Presentation @ *CBC Conference - Behaviour Change for Health: Digital & Beyond,* Feb. 2018

Office Workers' Perceived Barriers and Facilitators to Taking Regular Micro-breaks at Work: A Diary-Probed Interview Study, Oral Presentation @ the 12th *International Conference on Persuasive Technology*, Apr. 2017

How to Design Internet of Things to Encourage Office Workers to Take More Regular Micro-B, Oral Presentation @ the 34th *European Conference on Cognitive Ergonomics*, Sep. 2016

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Many thanks to my internal examiner, Prof. Chris Greenhalgh, and external examiner, Prof. Yvonne Rogers, for their time and comments, which have really helped improve the quality and impact of this thesis.

Among the colleagues, I would like to particularly thank Dominic Price, for volunteering over 10 months of his time, to iteratively develop and improve the *WorkMyWay* Android App, and patiently provide diagnostic and troubleshooting support over the study period. I would also like to thank Roma Patel for helping design and facilitate the stakeholder workshops, both the pilot one in Newcastle and the formal one in Nottingham, and thank Felicia Black for the administrative and publicity support. Thanks to the faculty at the Mixed Reality Lab for their constructive critique and advice: Anthony Brown, Max Wilson, Joseph Marshall, Paul Tennent, and Martin Flintham. Thanks to my industry supervisors for their advice and guidance both on my PhD research and placement at Unilever, Port Sunlight: Robert Treloar, Brian Newby, Richard Wright, and Hilde Hendrickx.

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Table of Contents

List of Tables

List of Figures

List of abbreviations

ACM	Association for Computing Machinery
APIs	Application programming interfaces
APEASE	Affordable, practical, (cost-)effective, acceptable, safe, and equitable
ATF	Automated tailored feedback
BAP	Brief action planning
BCI	Behaviour change intervention
BCT	Behaviour change technique
BCW	Behaviour Change Wheel
BIT	Behavioural intervention technology
BMI	Body mass index
CD	Connected device
CDT	Centre for Doctoral Training
COM-B	Capability-Opportunity-Motivation model of Behaviour
CPE	Count per epoch
DBCI	Digital behaviour change intervention
DL	Digital log
DPM	Dual process model
GBP	Great Britain Pound
HCD	Human-centred design
HCI	Human-computer interactions
ICT	Information and communication technology
ID	Information delivery
IoT	Internet of Things
JBI	Joanna Briggs Institute
JITAI	Just-in-time adaptive interventions
LPA	Light physical activity
MET	Metabolic equivalents
MI	Motivational interview
MoD	Mode of delivery
MOSSI	Mediated organizational support and social influences
MRC	Medical Research Council
MVPA	Moderate to vigorous physical activity

NHS	National Health Service
NPO	Non-profit organisations
OSPA	Occupational Sitting and Physical Activity
OSPAQ	Occupational Sitting and Physical Activity Questionnaire
PA	Physical activity
PDC	Passive data collection
PM	Prospective memory
PPI	Public and patient involvement
PT	Persuasive technology
RCT	Randomized controlled trial
RQ	Research question
SB	Sedentary behaviour
SCT	(Bandura's) Social Cognitive Theory
SDK	Software Development Kit
SP	Scheduled prompts
SRBAI	Self-Report Behavioural Automaticity Index
SRHI	Self-Report Habit Index
TDF	Theoretical Domain Framework
TEI	Tangible, embedded and embodied interactions
TPB	Theory of Planned Behaviour
UbiComp	Ubiquitous Computing
UCD	User-centred design
USB	Universal Serial Bus
WHO	World Health Organisation

Chapter One

Introduction

This chapter introduces the overarching aim of this doctoral research and establishes its importance in terms of meeting societal needs and making use of technologies. It first highlights health behaviour change as a valuable approach to tackle major challenges (e.g. sedentary behaviour, or SB) faced by the population and the society, and the importance of systematically applying theories to developing behaviour change interventions. Secondly, it overviews the latest technological revolution characterised by the Internet of Things, and introduces the design approach of enchanted objects and its promise for delivering health interventions in the workplace. Against this background, the overarching research aim and questions are proposed. The chapter then moves on to describe where the research sits in the academic world, introduces methodological frameworks guiding the research process, and concludes with a summary of research activities and upcoming contents in each thesis chapter.

1.1 A behaviour change approach to healthy living

The aging population in many countries including the United Kingdom (UK) means a growing number of people in potential needs of health and care services, which would place an increased financial burden on healthcare systems. However, many of the ill-health problems are behavioural in nature, rather than inevitable parts of aging (Fisher et al., 2011). Health-compromising behaviours, such as sedentary lifestyles, smoking, alcohol and substance abuse, require interventions with a focus on behaviour change. There is strong evidence that healthier lifestyle decisions can have positive impacts on people's health outcomes and quality of life, throughout their lifetimes and especially in old age (Harper et al., 2016). In view of the above, understanding and promoting health behaviour change is a worthwhile endeavour.

According to a Public Health England report, physical inactivity is one of the country's most urgent and costly challenges; motivating people to live an active lifestyle can prevent or delay the onset of many diseases or personal injuries, which is estimated to save the National Health Services (NHS) around 1 billion GBP and the wider society around 7.4 billion GBP a year (Public Health England, 2014). This includes not only savings on healthcare expenditures for individuals and families, but also economic benefits to employers and the broader economy. For instance, businesses with active workforce can benefit from higher productivity, less absenteeism due to sickness or repetitive strain injury, less presentism, and lower job turnover rates (Shrestha et al., 2015). Supporting office workers to intersperse seated work with regular breaks to recharge themselves both physically and mentally is crucial to sustainable utilisation of human resources and developing "socially sustainable" organisations (Pfeffer, 2010; Trougakos & Hideg, 2009).

The concept of "physical inactivity" in the aforementioned report (Public Health England, 2014) encompasses both excessive SB (i.e. activities with very low energy expenditure such as sitting) and insufficient exercise (i.e. lack of moderate to vigorous physical activity), which are considered independent health behaviours and require different interventional approaches (Pate, O'Neill, & Lobelo, 2008). This thesis tackles the challenge of the former, focusing on SB in office-based workplace settings. A justification will be provided in Chapter 2, along with a clarification on concepts and knowledge related to the issue.

1.1.1 The role of theory in behaviour change intervention design and research

As proposed by Biddle (2011), a key area in SB research should be identifying theories and perspectives most suitable for understanding and changing the target behaviour. Use of theories is important throughout the whole process of behaviour change intervention research, from analysis of behaviours, through intervention design, implementation to evaluation of process and effect (Moore et al., 2015). More extensive use of theory in behaviour change interventions is found to be associated with increase in effect size (Webb, Joseph, Yardley, & Michie, 2010).

It is positive that an increasing number of digital applications and devices aimed to promote healthy living are underpinned by theories of behaviour change, such as goal-setting theory and Transtheoretical Models (Consolvo, McDonald, & Landay, 2009; Herrmanny, Ziegler, & Dogangün, 2016). However, having a theory or two to back up the design decision does not qualify an intervention to be considered "theory-informed". As identified by a panel of interdisciplinary experts (Davis, Campbell, Hildon, Hobbs, & Michie, 2015), there are 83 theories of behaviour change, many of which have overlapping constructs (Michie et al., 2005). Therefore, the real challenge lies in selecting theories most appropriate and relevant to the behavioural problem of interest. This thesis seeks to adopt a genuine theory-informed approach to intervention development by following a systematic framework, which will be introduced in Section 1.5.

1.2 Digital technology for health and for behaviour change

Digital technology, or computing technology, refers to tools, systems, devices and resources that generate, store or process data in the form of digital signals (Oxford English Dictionary, 2019). The past two decades have seen an increasing number of digital technologies with various form factors (e.g. PC, tablets, smartphones, wearables, service robots, Internet of Things) entering people's everyday lives. Their potential for improving healthcare and delivering services has been demonstrated with a range of mHealth (mobile health) and uHealth (ubiquitous health, aka. pervasive health) examples (Free et al., 2013; Webb et al., 2010). The marriage between digital technology and behaviour change has also been promising and given rise to interdisciplinary fields such as digital behaviour change interventions (DBCIs) (West & Michie, 2016) and persuasive technologies (Fogg, 1999). It is believed that digitalisation of healthcare and behaviour change can potentially lead to considerable economical savings and positive societal impacts in the medium and long terms, despite their development cost in the short term (Harper et al., 2016).

Back in 1991, Mark Weiser envisioned a future where computing technologies will weave themselves into the fabric of everyday life and become so ubiquitous eventually that no one will notice their presence (Weiser, 1991). The exponential growth of computing power at a more affordable price has driven a technological revolution characterised by the Internet of Things (IoT). As IoT-enabled products and services with various form factors and interfaces (e.g. service robots, IoT appliances, ambient intelligence) are entering our everyday lives, they may represent a novel of mode of delivery for DBCIs. However, at the moment, the majority of DBCIs are still limited to using screen-based media; attempts to explore novel[1] digital interfaces for behaviour change beyond screens have been sporadic yet encouraging. Wearables that deliver tactile or audible idle alerts (e.g. FitBit, Jawbone) seem to be the most common and market-ready form of screenless persuasive technology. Developments of more novel interfaces for behaviour change mostly remain in the academic world and are exploratory in nature. These include ambient

[1] In the current PhD, the word "novel" is specifically used to describe screenless digital interfaces, interactions and interventions, although the author recognises the novelty of other types of interaction and that the meaning of novelty may change with time

persuasive designs that overlay or embed digital information in physical artefacts to influence behaviours and cognitions, consciously via provision of just-in-time information (Chi, Chen, Chu, & Lo, 2008; Haller et al., 2013; Intille, 2002; Jafarinaimi, Forlizzi, Hurst, & Zimmerman, 2005), unconsciously via techniques such as nudge and priming (Ham & Midden, 2010; Intille, 2002; Meschtscherjakov, De Ruyte, Fuchsberger, Murer, & Tscheligi, 2016; Pinder, 2017; Van Ittersum & Wansink, 2012), and both consciously and unconsciously (Rogers, Hazlewood, Marshall, Dalton, & Hertrich, 2010). Yet there is a lack of framework to guide the design of novel technologies for behaviour change.

1.2.1 An enchanted object approach

Enchanted object is proposed by Rose (2014) as a specific approach to design IoT interactive systems by making use of the physical form factor of ordinary everyday objects and "enchanting" them with embedded sensors, actuators, wireless transmitters and processors. According to Rose, enchanted objects have 7 abilities (i.e. glanceability, gestureability, usability, wearability, affordability, indestructibility and loveability) and are meant to serve fundamental human desires, such as the desire for "omniscience" and "immortality" (i.e. health). The glanceability and gestureability can be related to several broader concepts and frameworks in the HCI literature, which is summarised below.

First, the glanceability of enchanted objects suggests that they present the right amount of information at the opportune time and place, and demand little attention or cognitive efforts. The example Rose used to illustrate glanceability is the Ambient Orb, which is an IoT-enabled lightbulb that can be configured to glow in response a specified information source that the user cares about (e.g. high pollen count). The glanceability resonates with the design approach of ambient media (Ishii et al., 1998) in suggesting the use of peripheral cues to deliver information without overloading or intruding on the user. It also speaks directly to Weiser's vision of Calm Technology that supposedly moves easily between the periphery and centre of user's attention to inform and empower the user (Weiser & Brown, 1995).

As for gestureability, it means enchanted objects (Rose, 2014) should respond to the common gestures already used to manipulate those everyday objects, so that the user instinctively and naturally knows how to interact with enchanted objects. This is relevant to Norman's concept of affordance, referring the visual cues of an object that suggests how the object should be used (Norman, 1988). The gestureability reduces the cognitive processing required for learning and initiating interactions with IoT systems despite their novelty.

Not every enchanted object needs to have all 7 abilities, but design opportunities exist in thinking about ways to deliver those abilities by climbing up the "ladder of enchantment". The author is particularly inspired by the glanceability, gestureability and loveability of enchanted objects, and believes that they are promising mode of delivering health behaviour change interventions in office work, for the following reasons:

Frist, office workers are loaded with cognitive demands at work, which renders the glanceability and gestureability of enchanted objects particularly valuable. The glanceability strikes a balance between the subtlety and salience of communication and hence addresses the challenge of attention overload; the gestureability reduces the cognitive processing required to react to the technology.

Second, technology influences behaviour not only via explicit persuasions but also via embodied facilitation and constraints (Hornecker & Buur, 2006; Midden, Kaiser, & Mccalley, 2007). Although a smartphone notification may ***suggest*** the user to take a movement break, the physical property of a smartphone (i.e. usually located within easy reach to the user) and the virtual structure of the notification system (i.e. push notifications from multiple apps) indeed ***facilitate*** the action of continuing on-screen activities on the spot in a sedentary manner. In contrast, an enchanted object design may exploit the everyday use case of the ordinary object to get the user stand up, move to a different location and do something.

Third, the "screen guilt" experienced by office workers at work (Skatova et al., 2016) makes a strong case for choosing enchanted objects as a novel mode of delivery for workplace interventions, not only to reduce SB, but also to improve other health behaviour and mental health in the workplace, potentially in the future. The loveability of enchanted objects can be exploited for this purpose.

Fourth, unmentioned by Rose, embedding interventions in indispensable objects that are used on a daily basis means more user touchpoints, and potentially better engagement and longer adherence, which is crucial to the effectiveness of DBCIs (Perski, Blandford, West, & Michie, 2017).

Finally, the gestureability and affordance of objects seem to be related with goal activation and priming in cognitive psychology (Eimer & Schlaghecken, 2003), which is well-researched in laboratories but rarely applied in field studies. Details will be introduced in Chapter 2. In a nutshell, a goal is a mental representation of a desired end state, which can be activated (i.e. primed) and pursued at an unconscious level. (Bargh, Gollwitzer, Lee-Chai, Barndollar, & Trötschel, 2001). This suggests the future possibility of using different objects as primes to activate related goals at different timepoints throughout a workday in the office. More research is warranted to understand the feasibility and acceptability of this approach.

1.3 Research aim and questions

In view of the public health needs for reducing SB, and the exciting development of novel digital media that have the potential to advance behaviour change, the author proposes the overarching aim of the thesis, which is to advance our knowledge of how to reduce office workers' SB with the support of IoT technology.

The following research questions (RQ) are investigated:

RQ1: What intervention components can be used to reduce SB in office work, and through what theory-informed mechanisms of action[2]?

RQ2 Whether and how well can IoT-enabled smart objects deliver those intervention components and support those mechanisms of action?

1.4 Interdisciplinary context

Apparently, to address the above research aim calls for an interdisciplinary approach. Fortunately, the author is enrolled in an innovative, interdisciplinary PhD programme at the Horizon Centre for Doctoral Training with access to training and supervision resources across departments. As Horizon PhD students, we are highly encouraged to go beyond our home disciplines and bring together perspectives and methods from different

[2] Mechanisms of action can be a range of theoretical constructs and defined broadly as "the processes through which a behaviour change technique affects behaviour" (Michie et al., 2018).

disciplines. As Figure 1 illustrates, this PhD research sits at the intersection of 3 disciplines, namely health science, behaviour science and Human-Computer Interaction (HCI).

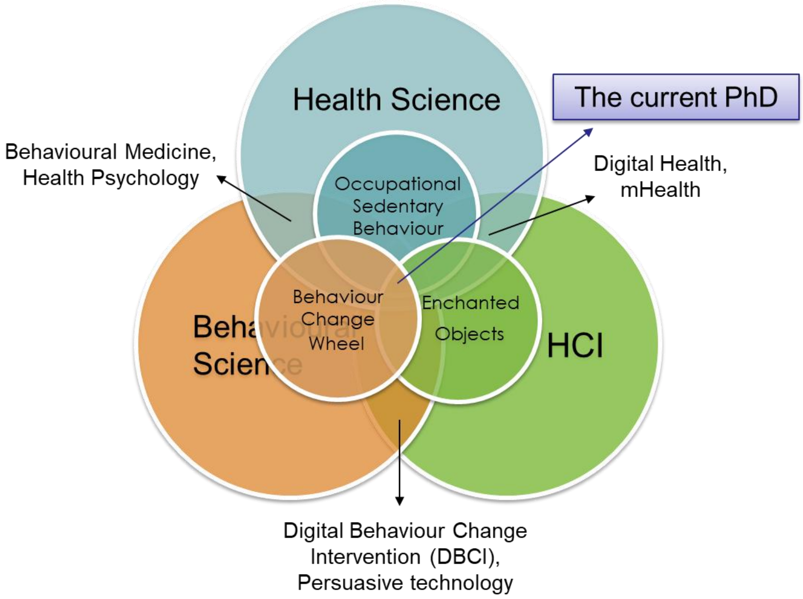

Figure 1 Interdisciplinarity of the doctoral research

The discipline of HCI is concerned with the design and research of interactions between computing systems and the user. It offers a repertoire of methods that will be used in the current PhD to elicit user requirements, analyse context of use, study and optimise user experience. The discipline of public health science is concerned with improving the quality of population health through identifying and modifying risk factors and making use of the current best evidence. The public health literature offers justifications for the current PhD (see a summary of epidemiological literature in Chapter 2). There is a long history of marriage between health science and behaviour science, which has led to the discipline of behavioural medicine that applies behaviour change theories to design interventions to influence real-life health behaviours. Hence, the field of behavioural medicine has a dual emphasis on theory and evidence, which is valuable and complementary to HCI research approach.

1.5 Methodological frameworks

1.5.1 Behaviour Change Wheel

First, to address RQ1, this research needs a framework to guide the elicitation of theory-informed design requirements and translating them into design of intervention contents.

As mentioned earlier, there is an overwhelming number of theories and techniques of behaviour change to choose from. Currently, the selection of theory in DBCI and persuasive technology design is heavily reliant on the designer's intuitive understanding of the behaviour and knowledge of the behaviour change theories, rather than following a systematic approach (Michie, Atkins, & West, 2014). This has the risk of excluding potentially relevant and viable theories and strategies of behaviour change (Francis et al., 2009). For instance, the widely known Transtheoretical Model and Health Belief Model are increasingly questioned for their failure to cover automatic motivational factors (e.g. impulses, habits, and emotions) that can be powerful drives for some behaviours (West, 2005). It also requires an in-depth understanding of the content of each theory and mastery of research techniques to collect and analyse data regarding the behavioural determinants to reach an informed design decision (Atkins et al., 2017). The Behaviour Change Wheel (BCW) (Michie et al., 2014) was recently developed to facilitate this process and was well received by research communities such as behavioural medicine and DBCI.

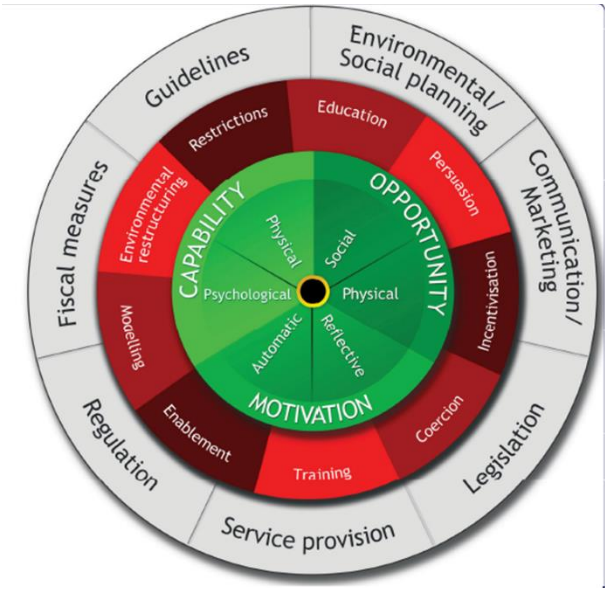

Figure 2 The Behaviour Change Wheel, figure from Michie et al. (2014)

As Figure 2 illustrates, at the centre of the wheel is the "COM-B" model of behaviour, that breaks down behavioural determinants into 3 dimensions (with 2 subcomponents in each aspect), namely Capability (psychological and physical), Opportunity (physical and social) and Motivation (automatic and reflective). COM-B is a simplified version of the Theoretical Domain Framework (TDF), which draws 128 key theoretical constructs from

33 behaviour change theories and groups them into 12 theoretical domains (Michie et al., 2005) (which were later refined to 14 domains (Cane, O'Connor, & Michie, 2012)). The compatibility with TDF backs the COM-B with theoretical rigour, as the TDF has been widely validated and used by psychologists to elicit and analyse data in numerous behavioural diagnostic studies (e.g. Francis et al., 2009; French et al., 2012).

The COM-B is surrounded by the red ring of 9 intervention functions, including education, persuasion, incentivisation, coercion, training, enablement, modelling, restriction, environmental restructuring, each of which addresses deficits in one or more of the 6 COM-B components. As those intervention functions are defined in very general terms, they are further delineated with 93 Behaviour Change Techniques (BCTs) (Michie et al., 2013) (e.g. "action planning", "social reward"), which are observable, replicable and irreducible "active ingredients" within an intervention designed to change behaviour. The outer grey ring of the BCW represents 7 policy categories, referring to the type of decisions made by authorities that help support and enact the interventions.

In a nutshell, the centre of the BCW supports rigorous behavioural diagnosis and identification of theories with a comprehensive and systematic framework of theoretical constructs. The outer rings of the BCW support translation of the behavioural diagnosis into intervention design, based on guides developed via expert consensus processes (Michie et al., 2014). The thesis chapters and sections with contents related to the BCW-guided intervention design process are summarised in Figure 3.

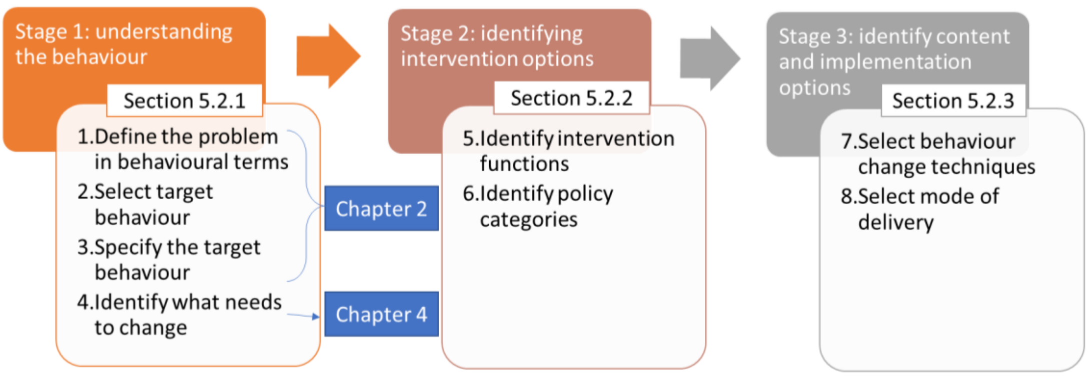

Figure 3 BCW-guided intervention design process, adapted from Michie et al. (2014) p.31

1.5.2 Human-centred design approach

The BCW has limitations when it comes to designing specifics about the digital mode of delivery for DBCIs. To address RQ2, methods and methodologies from HCI can be a valuable complement. The human-centred design (HCD) (aka user-centred design, or UCD) methodology encompasses a large and complex set of user study and design methods that originate from several fields such as software engineering, product design, and interaction design, which will be collectively called "HCI" throughout the thesis. The HCD demands a clear understanding of user requirements and context of use to inform design, and encourages active involvement of potential stakeholders in the design process, which is in consistency with the BCW's values in terms of making interventions relevant to the local context and acceptable to stakeholders (Davis, 2009; Gram-Hansen, 2016; Mackenzie et al., 2015). Hence, the author will adapt and embed the appropriate HCD methods in studies and design activities throughout the PhD with a pragmatic attitude.

1.5.3 UK Medical Research Council guidance on complex intervention

Finally, from a public health perspective, it is important to position the work conducted in this PhD in the big picture of potentially improving health outcomes and benefiting the wider population at scale in the future. Hence, the UK medical research council (MRC) guidance on developing and evaluating complex interventions (Campbell et al., 2000; Craig et al., 2008, 2019) was used to frame and communicate research outputs to the audience in the health science community. The guidance summarises 4 phases in the process of developing complex interventions and the key functions/activities at each phase (Figure 4). The work documented in Chapter 2 through to Chapter 5 in the thesis is all situated in the development phase; the process evaluation study in Chapter 6 is situated in the feasibility/piloting phase, with a focus on testing feasibility and acceptability of the research and intervention procedures, including the technology for data collection and intervention delivery.

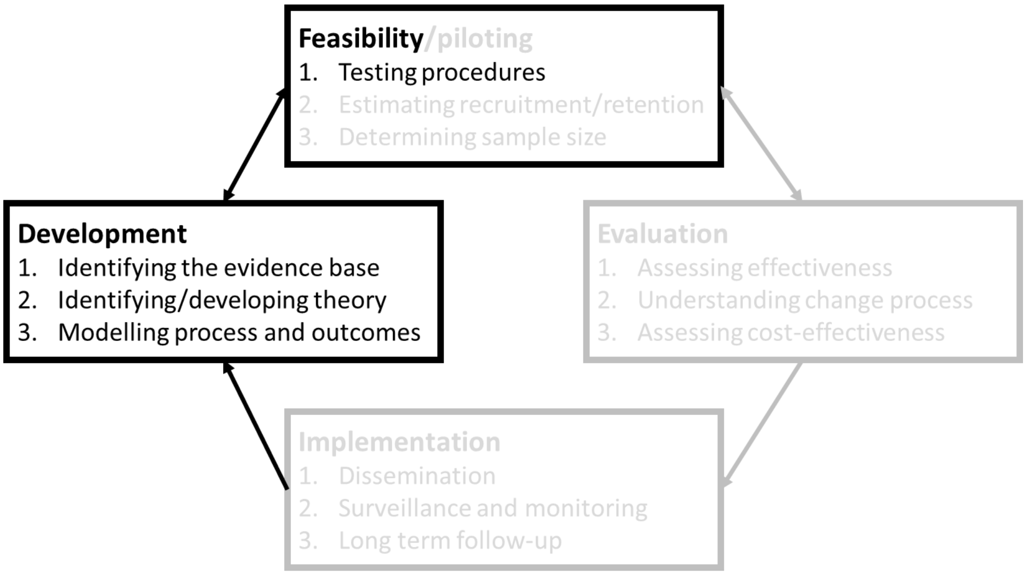

Figure 4 MRC guidance on developing and evaluating complex interventions, adapted from (Craig et al., 2019)

1.6 Research process and thesis structure

Figure 5 summaries the thesis structure, research process and sub-questions addressed, and methods/methodologies used in each design and research activity. The thesis has 7 chapters.

Chapter 2 will first clarify on epidemiological concepts related to SB (e.g. definition, measurement, biomarkers, consequences, prevalence, determinants) to facilitate understanding of work presented in subsequent chapters; in addition, it specifies the target behaviour (i.e. prolonged stationary behaviour of office workers in the workplace), which fulfils the initial steps in the BCW-guided intervention design process (i.e. orange boxes in Figure 4). Chapter 3 will present a systematic scoping review on existing digital interventions to reduce office workers' SB. Chapter 4 will present a COM-B/TDF analysis of office workers' prolonged SB using data from a diary-probed interview study with 20 office workers, as part of the BCW-guided intervention design process.

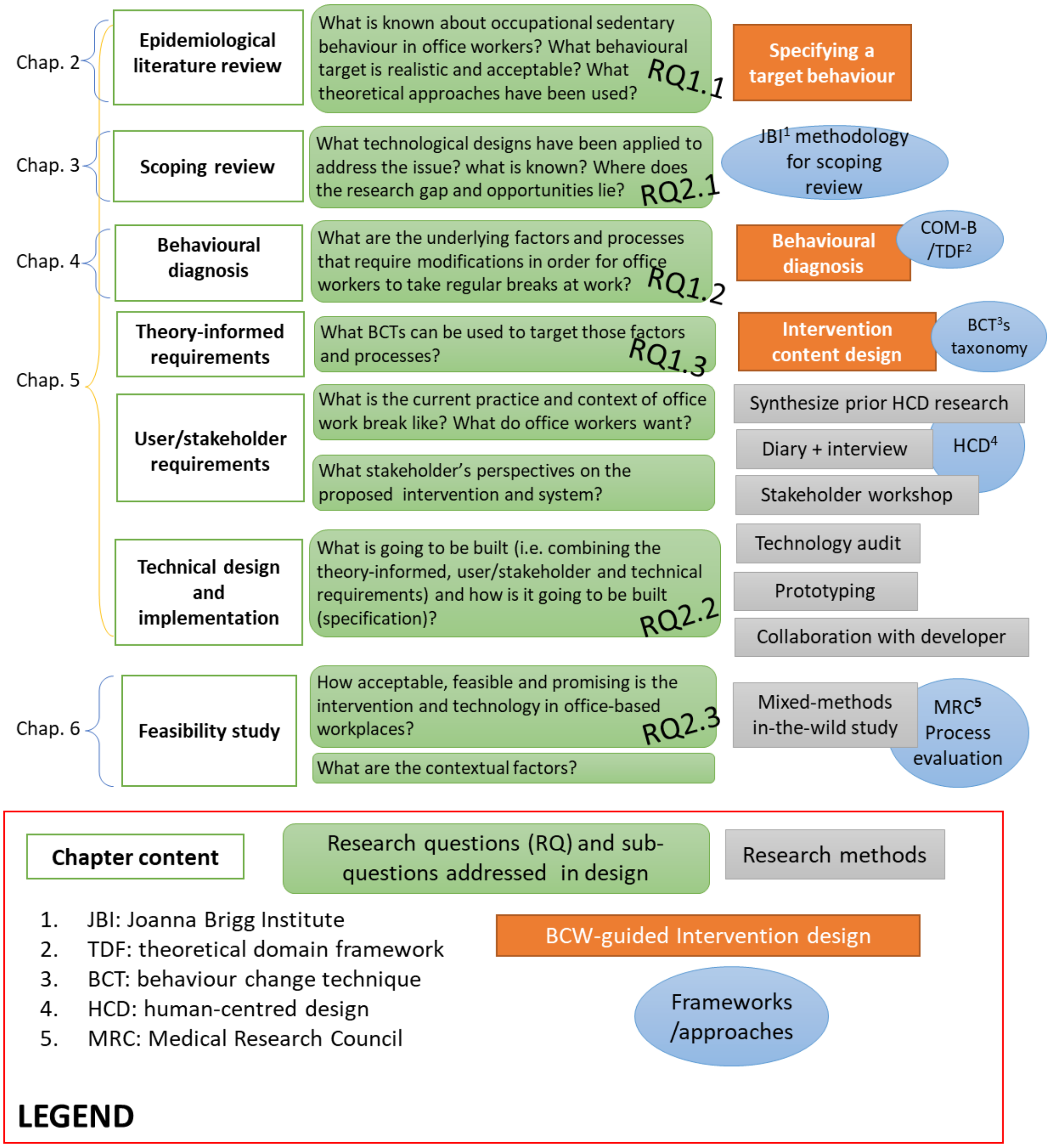

Figure 5 Research summary and thesis structure

Chapter 5 will document the design and development of the intervention *WorkMyWay*, including the intervention content and technological delivery system. Some data from previous chapters will be summarised in Chapter 5 as part of the BCW-guided intervention design process, and some data re-analysed or presented through the lens of HCD to offer insights into user requirements and the context of office work breaks. New data from a design workshop with stakeholders will also be reported. The technical design and implementation will be detailed. The chapter concludes with a description of the final implementation of *WorkMyWay*, which brings together 3 sets of requirements (theory-informed, user-centred, and technical). While presented in a linear manner for clarity, the actual design and development process was iterative, which will be revisited at the end of Chapter 7.

Chapter 6 will report the feasibility and acceptability of *WorkMyWay,* assessed with an 8-week (2-week baseline + 6-week intervention) mixed-methods study with 15 office workers in office-based workplaces. Based on the MRC guidance on process evaluation (Moore et al., 2014), the study will look at dimensions such as quality and quantity of intervention delivery, promise for behaviour change and the mechanisms through which it can potentially change the behaviour, contextual factors affecting the use and potential effectiveness.

Chapter 7 will synthesise the core findings from individual chapters to answer the research questions and weave together the main threads of the thesis into a broader discussion of contributions in 4 key areas.

Chapter Two

Occupational sedentary behaviour: essential knowledge

2.1 Introduction

Chapter 1 establishes that reducing sedentary behaviour (SB) have benefits for individuals, organisations, and the wider society. This chapter provides essential epidemiological knowledge to facilitate understanding of work presented in subsequent chapters. Based on a comprehensive behavioural epidemiology framework, Owen (2012) proposed the following agenda for SB research; the thesis chapters and sections that correspond to Owen (2012)'s agenda items are specified with notes in brackets.

1. SB, biomarkers and health outcomes: dose-response; mechanism (Section 2.3)
2. Measurement development for SB (Section 2.2 and Chapter 5)
3. Characterizing population prevalence, trends and variations in SB (Section 2.3)
4. Identifying the relevant determinants of SB in multiple contexts (Section 2.5 and Chapter 4)
5. Conducting laboratory and field-based intervention trials on SB change (Chapter 6)
6. Informing and evaluating large-scale innovations and policy initiatives (Chapter 6)

Specifically, Section 2.2 in this chapter will introduce the definition and measurement of SB, which corresponds to Agenda Item 2 and informs the technology developing presented in Chapter 5. Section 2.3 will summarise research on the health outcomes and prevalence of excessive SB in office-based workplaces, which corresponds to Agenda Item 1 and 3, and justifies the importance of this doctoral research. Section 2.4 maps interventions onto a physical activity continuum based on behavioural targets, with the aim to specify what behaviour the current PhD project should realistically and preferably target. Section 2.5 reviews previous research on determinants of SB in office-based workplaces and introduces potentially applicable theories, which corresponds to Agenda Item 4; however, the decision on theories for use in the current PhD project will be made after the behavioural diagnosis study presented in Chapter 4.

In addition, this chapter fulfils Step 1 to 3 in the Behaviour Change Wheel (BCW)-guided intervention design process (Figure 3).

2.2 Definition and measurement

The past decades have seen a rapid rise in research and literature on SB in several disciplines including human physiology, epidemiology and behavioural medicine. Researchers used to describe people or lifestyles that lack moderate-to-vigorous physical activities (MVPA) as being "sedentary". For example, in the well-known cohort study of Harvard Alumni, subjects burning less than 2000 kcal per week through walking, climbing stairs and playing sports were classified as "sedentary" subjects (Paffenbarger, Hyde, Wing, & Hsieh, 1986). However, in recent decades, researchers have drawn a clear distinction between "sedentary behaviour" and "a lack of exercise" (Van Uffelen et al., 2010), considering them as independent exposures that can co-exist in one subject (Pate et al., 2008).

According to a terminology consensus project by the Sedentary Behaviour Research Network (Tremblay et al., 2017), SB is most commonly defined as "any waking behaviour characterised by an energy expenditure of less than 1.5 metabolic equivalents (METs), while in a sitting, reclining or lying posture". One MET equals the energy cost of resting quietly (Ainsworth et al., 2011). Light physical activity (LPA) involves an energy expenditure of 1.6 – 3 METs and includes activities such as standing, slow walking and so on. Apparently, the definitions have dual components, specifying both energy expenditure and posture. The 1.5 MET intensity threshold is deemed broadly appropriates as the cut-off point between sitting and standing activities in healthy and overweight adults, although some sitting activities such as typing and writing, could sometimes incur an energy expenditure above 1.5 MET (Tremblay et al., 2017).

The development of automated wearable sensors opens up new research possibilities, by offering methods that allow fine-grained and continuous measurement of the entire range of waking activities in the wild. However, several methodological issues are worth attention as they have implications for intervention design. Self-report or direct observation methods that operationalise sedentary time as time spent in activities performed in sitting or lying postures (e.g. van Nassau, Chau, Lakerveld, Bauman, 2015 & van der Ploeg, 2015) are considered generally acceptable. However, unlike human observations or self-report, activity monitoring devices determine wearers' postures indirectly based on the rotational velocity of, or gravity force acting on, certain body segments (e.g. hip, waist). Such data need to be captured with gyroscopes, or 3D accelerometers worn as close to those body segments as possible. This means an inevitable trade-off between the wearer's comfort and the accuracy of activity detection. Wrist-worn activity monitors are thought to be broadly acceptable in the general population, and offer the likelihood of better adherence to wear time protocol than devices that are worn at other body parts (Brakenridge, Healy, Winkler, & Fjeldsoe, 2018; Rowlands et al., 2016). However, wrist-worn ambulatory monitors are incapable of telling accurately whether the wearer is sitting or standing, because one's wrist can incline in any direction despite body posture. Although sitting can be possibly differentiated from standing based on the 1.5 MET energy expenditure cut-off point, it should be noted that the most commonly used activity monitors in epidemiology (e.g. *ActivPAL* and *actiGraph*) determine energy expenditure indirectly via ambulatory intensity, rather than directly via physiological intensity, the measurement of which would require biomechanical and physiological sensors (e.g. heart rate, oxygen intake sensor). Hence, it has been suggested that "sedentary time" collected from an accelerometer that does not measure posture should be reported as "stationary time", which is a classification home for time spent on non-ambulatory activities that include both sitting and standing (Tremblay et al., 2017).

2.3 Prevalence and health outcomes

In the past decade, ample evidence has accumulated to suggest the unfavourable association between SB and cardiometabolic health, even after adjusting for the amount of MVPA (Bankoski et al., 2011; Brocklebank, Falconer, Page, Perry, & Cooper, 2015; Dunstan, Howard, Healy, & Owen, 2012; Henson et al., 2013; Lynch, 2010). Moreover, the amount of sedentary time accumulated in single bouts that last longer than 30 min (i.e. sustained sedentary bouts) or 60 min (i.e. prolonged sedentary bouts) add to the risks, whereas breaks in sedentary time are beneficially associated with metabolic biomarkers (Brocklebank et al., 2015; Healy et al., 2008).

With large proportions of the population moving from jobs involving physical activity to sedentary occupations – defined as "jobs involving more than 6 hours of sitting on an 8-hour workday and only occasionally walking, standing and lifting of no more than 10 pounds at a time" (social security administration, 1980) – in the last half century, occupational sitting has increasingly become a public health concern (Buckley et al., 2015). Based on studies with Australian and UK office-based workers, occupational sitting contributed more than half of total sedentary time on workdays (Bennie et al., 2015; Clemes, Oêconnell, & Edwardson, 2014; Parry & Straker, 2013; Thorp et al., 2012). Self-report and accelerometer studies have consistently demonstrated office workers spend most (varying from 60% to 82% across studies) of their working hours on sitting (Clemes et al., 2016; Fountaine, Piacentini, & Liguori, 2014; Ryan, Dall, Granat, & Grant, 2011; Waters et al., 2016); moreover, office workers' within-work time is characterised by more sustained (12% -34.8% of total sitting) and prolonged (25% - 49.8% of total sitting) sedentary bouts with fewer breaks than non-work time (Parry & Straker, 2013; Ryan et al., 2011). This makes the office-based workplace a priority setting for interventions targeting SB reduction, for both health and productivity gains (Buckley et al., 2015).

2.4 Interventional approaches and behavioural targets

A variety of interventional approaches with potential for SB reduction are reported in the literature. This section reviews the approaches and behavioural targets adopted in existing interventions and discusses what behaviour can be realistically targeted in this PhD project.

Before introducing each of the approaches, it is worth pointing out that much information on SB reduction can be found in the well-established field of research that targeted physical activity (PA) promotion as the primary outcome while reporting SB reduction as a secondary outcome (Compernolle, Vandelanotte, Cardon, De Bourdeaudhuij, & De Cocker, 2015; Marshall, Leslie, Bauman, Marcus, & Owen, 2003). This suggests an overlap as well as distinction between SB reduction and PA promotion interventions. As previous researchers have classified waking behaviours based on activity intensities into SB, LPA, and MVPA, which can be mapped onto a continuum (Ainsworth et al., 2011). In order to better relate the many examples of previous interventions in this area, the author proposes a graphical representation (Figure 6), where broad interventional approaches (e.g. PA promotion, SB reduction, sit-stand desk, break-focused, step count-focused interventions) are overlaid onto the existing physical activity continuum, with arrows indicating the directions of change targeted by each approach.

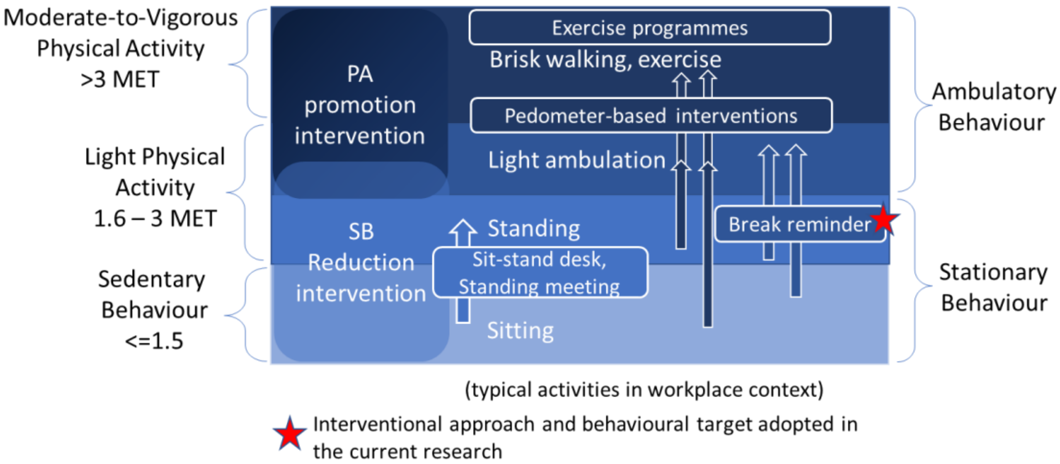

Figure 6 The intervention continuum: from SB reduction to PA promotion

The majority of conventional PA promotion interventions address the higher end of the continuum by encouraging people to exercise more at the level of MVPA. SB is an independent exposure in a sense that an individual who engages in > 150 min of MVPA every week and meets conventional public health guidelines for adults' PA (National Health Service UK, 2018) can still have a high exposure to SB in the remaining waking hours. Although a recent meta-analysis (Sugawara & Nikaido, 2014) indicates 60–75 min of MVPA per day seems to offset the increased health risks associated with sitting for more than 8 hours per day, this amount of MVPA is notably beyond the recommended levels of MVPA in most public health guidelines (National Health Service UK, 2018; WHO, 2010) and hence a unrealistic behavioural goal for the general public, especially those employed on full-time office-based occupations.

Indeed, some workplace PA interventions have shifted focus from MVPA to aim for an increase in the middle-range activities (e.g. light ambulation), for example, by providing pedometers to employees along with tips and encouragement for achieving daily step goals (Freak-Poli, Wolfe, Backholer, de Courten, & Peeters, 2011). Many of those pedometer-based interventions have proved acceptable to office workers and successfully led to SB reduction as a secondary outcome (Parry, Straker, Gilson, & Smith, 2013; Puig-Ribera et al., 2017).

Although PA interventions can be potentially used to reduce SB, 2 published systematic reviews suggest that interventions specifically targeting SB were more effective in reducing SB than those targeting PA or a combination of PA and SB (Martin et al., 2015;

Prince, Saunders, Gresty, & Reid, 2014). This was potentially due to the disparate natures of the 2 behavioural targets – compared with PA, SB tends to be longer in duration, more pervasive, habitual and effortless, and involves much less conscious processing (Biddle, 2011). Section 2.5.3 will elaborate on the habitual nature of SB.

As far as SB-focused interventions are concerned, a large portion of the empirical work featured height-adjustable sit-stand desks (e.g. Gao, Nevala, Cronin, & Finni, 2015) or other types of active workstations (e.g. Carr et al., 2014). According to existing systematic reviews, such environmental strategies have proved successful in reducing workplace sedentary time (Chau et al., 2014), and even more effective when combined with behavioural, educational and organisational support strategies in multi-component interventions (Chu et al., 2016). However, concerns arise as a recent trial found the provision of height-adjustable workstations only induced an increase in standing without significantly changing ambulatory PA (Edwardson et al., 2018), the effects of which on cardiovascular risk biomarkers was found clinically negligible (Hawari, Al-Shayji, Wilson, & Gill, 2016); moreover, evidence suggests prolonged standing induces a range of adverse impacts on health outcomes and cognitive performance (Baker et al., 2018; Waters & Dick, 2015). Last but not least, the feasibility and scalability of active workstations are questionable, considering their costs to organisations (Neuhaus, Healy, Dunstan, Owen, & Eakin, 2014) and a lack of portability which makes them unsuitable for mobile and remote knowledge workers who perform seated work in different locations, ranging from home office, client office to public transport, café and so on (Greene & Myerson, 2011). Therefore, research is called for to explore novel and economical alternatives to sit-stand desks (Biddle & Bennie, 2017).

Interspersing sedentary time with regular LPA breaks has been proposed as a third interventional approach and deemed beneficial and achievable for the vast majority of adults (Mansoubi, Pearson, Biddle, & Clemes, 2014). Although no consensus has reached regarding the optimal interval and duration of breaks in sedentary work, expert advice and interventions have variably promoted behavioural targets, ranging from "a 2- to 3-min LPA break in every 30 min of sitting" (NHS, 2016) to "a 5-min LPA break in every 60 minutes" of sitting (Owen, Bauman, & Brown, 2009). Most of the currently available evidence suggests breaks in sedentary time confer metabolic benefits and potentially other health benefits (Bankoski et al., 2011; Chastin, Egerton, Leask, & Stamatakis, 2015;

Henson et al., 2013; Lynch, 2010; Thorp, Kingwell, Owen, & Dunstan, 2014; Tremblay, Colley, Saunders, Healy, & Owen, 2010). A proposed mechanism is that sedentary breaks that usually involve LPAs like standing or walking restores the glucose and insulin regulation that is adversely associated with prolonged sitting (Dempsey et al., 2017; Dunstan et al., 2010).

On the other hand, although evidence is mixed regarding whether sitting-to-stepping reallocation is more beneficial than sitting-to-standing reallocation (Bailey & Locke, 2015; Healy, Winkler, Owen, Anuradha, & Dunstan, 2015), what is certain is that both prolonged sitting and standing should be avoided and broken up regularly with alternative activities (Baker et al., 2018; Buckley et al., 2015). In view of this, and the relative ease of quantifying stationary time with wrist-worn accelerometers elaborated in Section 2.2, it is decided that the intervention developed in the current PhD project will target a reduction in total and prolonged **stationary behaviour** (a combination of sitting and standing) rather than sedentary behaviour[3] alone.

2.5 Determinants of sedentary behaviour

Designing an effective behaviour change intervention usually requires a comprehensive understanding of the determinants and levers for the target behaviour change (Michie et al., 2014). A number of studies have contributed to understanding the motivators and barriers of reducing and breaking up SB. The MRC framework recommends intervention designers develop a theoretical understanding of the likely process of change by drawing on existing evidence and theory, and supplement it with new primary research if necessary (Craig et al., 2019). This section reviews prior research on determinants of SB, especially in the context of office-based workplaces.

2.5.1 Social ecological approach to sedentary behaviour

According to Prapavessis, Gaston, & DeJesus (2015), workplace SB intervention started with no exploration of determinants of the behaviour; early attempts to explore determinants of employees' work health behaviours started with an social ecological model or approach (Sallis et al., 2006; Sallis, Owen, & Fisher, 2008) that views behaviour

[3] In the remaining parts of the thesis, phrases such as "sedentary behaviour" and "sitting" will continue to be used, because they are more familiar than "stationary behaviour" to researchers working in this field.

as a result of an interplay between the individual, social, environmental and policy factors. For instance, a survey study with a sample of 801 Australian office workers followed the social ecological approach and aimed to identify individual, social, physical and policy environmental correlates of short PA break frequency; though the only 2 significant variables identified were both individual-level factors (i.e. perceived lack of time and lack of information about taking short breaks) (Bennie, Timperio, Crawford, Dunstan, & Salmon, 2011). A recent study with a sample of 105 UK office workers found variance in accelerometer-measured occupational PA could be explained with perceived management discouragement of breaks, but not any other social or environmental factor (Sawyer et al., 2017). A focus group discussion guided by the social ecological model revealed important determinants of workplace SB including the nature and scope of job, workplace culture and norms as well as physical environment and building infrastructure, even though the small sample size (n=6) limited the generalizability of the findings from this particular study (Waters et al., 2016).

Social ecological model-framed interventions are typically multilevel. For example, the intrapersonal level can be targeted via the provision of one-to-one educational and coaching sessions delivered either face-to-face or via digital mode of communication (Neuhaus, Healy, Fjeldsoe, et al., 2014), technological tools supporting behaviour change such as activity monitors and platforms with automated tailored feedback (Brakenridge et al., 2016); social norms and organisational culture supportive of regular break behaviours can be fostered via Group Motivational Interview (Coffeng et al., 2014), information sessions, and consultation workshops with organisational stakeholders, and the involvement of managers as workplace champions in health initiatives (Brakenridge et al., 2016; Neuhaus, Healy, Fjeldsoe, et al., 2014); physical environmental factors can be modified by installing relaxation facilities or active workstations (Coffeng et al., 2014; Neuhaus, Healy, Fjeldsoe, et al., 2014).

The social ecological model is also useful for unpacking multilevel impacts of interventions and revealing unexpected mechanisms of change. For example, Cooley and colleagues (Cooley, Pedersen, & Mainsbridge, 2014) conducted a qualitative study to explore participants' experience of a work health intervention. Although the intervention targeted primarily individual-level change via delivery of computerised break prompts, a social ecological approach allowed the researchers to comprehensively cover intervention impacts that occurred at the levels of mesosystem (e.g. increased social interactions and break behaviours becoming more acceptable in the workplace) and exosystem (e.g. increased awareness of prolonged sitting as a work health issue in the organisation), in addition to the microsystem level (e.g. changes in individual's perception and practice).

2.5.2 Socio-cognitive theories of sedentary behaviour

Although the structural constraints are important considerations in designing workplace SB interventions, the social ecological approach lacks a thorough analysis of the psychological processes underlying sedentary intention and behaviour.

This gap is continuously being filled, starting with research that applies the theory of planned behaviour (TPB) to explaining self-reported sitting and PA in the workplace. The TPB posits attitude, subjective norms, perceived behavioural control are important socio-cognitive constructs that influence behavioural intention, which in turn influences the behaviour (Ajzen, 1991). Just as the usefulness of the TPB itself in health psychology has been debated over the years (Armitage, 2015; Sniehotta, Presseau, & Araújo-Soares, 2014), evidence and counterevidence for the relevance of TPB to SB are co-existing. Cross-sectional studies (Prapavessis et al., 2015; Rhodes & Dean, 2009) have used multivariate analyses to demonstrate the relevance of intentional and cognitive processes to SB, in both leisure and non-volitional (including work and school) contexts, and found the relationship to be even more prominent in non-volitional contexts (Prapavessis et al., 2015; Warner & Biddle, 2011). However, counterevidence from another study suggested the inapplicability of TPB constructs to predicting occupational sitting, compared with socio-demographic and work-related characteristics (De Cocker, Duncan, Short, van Uffelen, & Vandelanotte, 2014). Though it was potentially due to the fact that the sample included a wide range of occupations and hence the socio-demographic and occupational characteristics could have confounded the relationships between TPB constructs and SB (e.g. more educated individuals tend to hold positive attitudes toward sitting less, but are also more likely to be employed in desk-based sedentary occupations). Another limitation of the study was a lack of process to elicit common beliefs on the TPB constructs, resulting in the low agreement scores across most psychological items, as reported by the researchers (De Cocker et al., 2014). A recent TPB-framed belief elicitation study with 105 UK office workers (Niven & Hu, 2018) adopted a qualitative approach and revealed a comprehensive set of commonly held beliefs regarding reducing workplace sitting. The study indicates UK office workers' attitudes towards sitting less is characterised by a mixture of perceived health benefits and productivity loss; it also suggests a workplace culture and norm supportive of sitting reduction is perceived as an important determinant of occupational sitting behaviour by office workers but is yet to be fostered.

The TPB-based constructs can find their overlap with some constructs in Bandura's Social Cognitive Theory (SCT). The SCT (Bandura, 2004) suggests the following constructs are underpinning health motivation and behaviour: outcome expectations (overlapping with attitude), perceived self-efficacy (overlapping with perceived behavioural control), goal, and perceived socio-structural facilitators and impediments (overlapping with subjective norms and affecting perceived behavioural control). However, the SCT differs from the TPB in that it does not only explain and predict behaviours, but also incorporates the techniques of change. For instance, the model suggests self-efficacy, which is central to the model, can be enhanced via mastery experience, vicarious learning, verbal persuasion (Bandura, 1986), goal setting and social support (Bandura, 2005).

Given the overlap of constructs between the TPB and SCT, they have been applied together to the planning, development and evaluation of workplace SB reduction interventions. Strategies such as self-monitoring of sitting behaviour, goal setting, action planning, problem solving have been used to enhance workers' perceived behavioural control or self-efficacy to sit less at work (Carr et al., 2015; De Cocker, De Bourdeaudhuij, Cardon, & Vandelanotte, 2016; Hadgraft et al., 2017; McGuckin, Sealey, & Barnett, 2017). Encouraging emails from managers have been used to change the perceived structural facilitators and subjective norms about sitting and break behaviours (Carr et al., 2015; Hadgraft et al., 2017). However, the SB research field still falls short of evidence on the mediating effects of TPB and SCT constructs in temporal changes in sedentary time (Owen et al., 2011; Rhodes, Mark, & Temmel, 2012). In the field of PA promotion, this has been accumulated with interventional or longitudinal, prospective studies, where SCT constructs are measured as mediating variables and included in structural models of causal pathways of behaviour change (Bauman, Sallis, Dzewaltowski, & Owen, 2002). In the aforementioned example, while the intervention targeting TPB and SCT constructs resulted in a post-intervention increase in those construct variables, sitting reduction was only partially (10%) mediated by one of the construct variables – perceived behaviour control (Hadgraft et al., 2017). This suggests factors such as subjective norms and attitudes could be only pre-conditions, rather than key enablers, of SB change in the workplace.

Cross-sectional studies have demonstrated the relevance of several other socio-cognitive theories to sedentary behaviours (e.g. Protection Motivation Theory - (Wong, Gaston, DeJesus, & Prapavessis, 2016); Organismic Integration Theory, a sub-theory of Self-Determination Theory - (Gaston, De Jesus, Markland, & Prapavessis, 2016)). The author will not go into depth to review and discuss findings from those studies. In brief, they all shed light onto the conscious and reflective cognitive and motivational processes underlying SB.

2.5.3 A dual-process perspective on sedentary behaviour

The findings that the common socio-cognitive constructs only partially explained variance in workplace sitting and sitting reduction intrigue researchers to identify a comprehensive cognitive model of SB. One of such potentially viable models is the dual-process model (DPM).

The DPM proposes human behaviours are regulated by both Type 1 and Type 2 systems (Deutsch & Strack, 2006). On one hand, the Type 1 system is reflective, conscious, rational, and controlled, and involves psychological constructs largely covered by the socio-cognitive theories (e.g. SCT, TPB). On the other hand, the Type 2 system is automatic, unconscious, impulsive, and uncontrolled and involves emotions and impulses that arise from associative learning (e.g. classical and operant conditioning) and/or innate dispositions. When it comes to self-regulation, the power of reflective system to suppress the automatic system could be weakened under circumstances, such as high cognitive demands, low working memory capacity, ego depletion and contextual cues for habitual behaviours (Hofmann, Friese, & Strack, 2009).

2.5.3.1 The role of habit in sedentary behaviour

Habit, or the learned impulse to perform a particular behaviour triggered automatically under a particular context, is one of the important constructs belonging to the automatic motivational system. The early definition of habits as "stimulus-response (S-R) associations acquired through repetitions" was deeply rooted in behaviourism (Aarts, Paulussen, & Schaalma, 1997). According to this definition, once a habit is formed, exposure to a contextual cue (S) can efficiently activate an impulse to perform the habitual behaviour (R), without the involvement of consciousness or intentionality (de Vries, Aarts, & Midden, 2011). In line with the behaviourist definition, early research on the role of habit in behaviour has demonstrated how frequently performed behaviours are less predictable by intentions (Bentler & Speckart, 1979; Ouellette et al., 1998) and how habits moderate the intention-behaviour relationships (de Vries et al., 2011; Gardner, Phillips, & Judah, 2016).

In the past decade, there has been a spurt of research interest in applying the habit theory to studying and modifying SB. Consistent with the behaviourist perspective on habit, much research has been focused on proving how sedentary time is better predicted by the strength of sedentary habit than socio-cognitive constructs such as attitude and intention (Conroy & Maher, 2013; Kremers & Brug, 2008; Maher & Conroy, 2015, 2016; Smith et al., 2018; Warner & Biddle, 2011). Based on a systematic review (Rollo, Gaston, & Prapavessis, 2016), there is consistent evidence that strong sedentary habits, measured using the self-report habit index (SRHI) (Gardner, Abraham, Lally, & de Bruijn, 2012; Verplanken & Orbell, 2003) as the tendency to engage in SB automatically without conscious thinking, is a significant risk factor for both total and context-specific sedentary time.

The office-based workplace is described as "particularly conducive to the formation of habitual responses" because of the unvarying physical environment and routinised nature of much office work (Gardner, De Bruijn, & Lally, 2011; Gardner, Smith, & Mansfield, 2017). Office workers perceive habit as a common, important barrier to reducing workplace sitting, despite generally positive attitudes and outcome expectancies towards sitting less at work (De Cocker, Veldeman, et al., 2015; Nooijen et al., 2018). A recent cross-sectional study (Smith et al., 2018) offers the empirical evidence that stronger automatic tendency to be active without conscious thinking (measured with the SRHI scale (Gardner et al., 2012)) in the workplace, is associated with more accelerometer-captured sit-to-stand transitions.

Interventional approaches focused on environmental manipulation alongside behavioural prompts, rather than conscious processing have been proposed as the approach to address the habitual nature of SB (Biddle, 2011). Examples of such habit-based interventions include smartphone Apps or computer software that deliver regular prompts for sedentary breaks (Cooley & Pedersen, 2013; Swartz et al., 2014) and restructuring of the physical and social environment in the workplace to remove or alter the contextual cues for prolonged sitting habits (Neuhaus, Healy, Fjeldsoe, et al., 2014).

While those habit-based interventions have shown some promise for SB reduction, they are limited by an inherent drawback of the behaviourism itself – they dismiss the role of cognition in habit, and regards habitual responses to the environmental stimulus as inflexible and mechanical (Wood & Neal, 2007). However, as suggested by several lines of cognitive experimental psychology research over the past decades, habits are not just behaviours directly controlled by the environment, as in S-R behavioural psychology, but are instead complex knowledge structures or associative memories centred on goal constructs (Bargh & Ferguson, 2000). The next subsection will introduce cognitive psychology literature on goal and habit and discuss their relevance to office workers' occupational sitting behaviour.

2.5.3.2 Modern habit theory from cognitive psychology perspective

Goal, as a cognitive scientific term, refers to the mental representation of a desired outcome or end state (Kruglanski, 1996). As frequently pursued goals are associated with memories of actions instrumental in attaining the goals, a habit can be conceptualised as a goal-directed knowledge structure that includes mental representations of the contextual cue, the desired outcome, and means for achieving the outcome or goal in the context in the past (Aarts & Dijksterhuis, 2000). An active health-promoting goal is essential in facilitating habit formation and maintenance by motivating repeated responses to the environmental stimulus over time until an automated association is developed (Wood & Neal, 2007).

For instance, the same office environment can be associated with both a "work achievement" goal and a "work health" goal. To initiate a healthier break habit, it requires the health-related goal (e.g. reduce SB) to be salient and shielded from other potentially conflicting goals (e.g. complete work sooner) at points of behaviour (Austin & Vancouver, 1996). A recent study found even though many office workers recognized health and wellbeing benefits of taking regular moving breaks, very few breaks in the moment were actually driven by the health-related goals (Luo et al., 2018). The researchers suggested future design should help people develop associations between the long-term health benefits of reducing prolonged sitting and immediate actions of taking movement breaks (Luo et al., 2018).

Indeed, a limitation with the majority of existing habit-based workplace SB interventions (e.g. Cooley et al., 2014; Thomas & Bond, 2015) is that they only focused on providing the cue for a target response (e.g. take a break), without incorporating strategies to address the accessibility and reward value of the associated goal in the situation. Prompts can work in the absence of an active goal if the individual has already formed the habit to take breaks in response to prompts at work; however, for those without the habit or with the alternative habit of sitting through to complete work despite any cue, introducing new prompts/cues alone would not suffice to break the old habit and start a new habit in the first place.

2.5.3.3 Strategies to heighten goal accessibility to drive habit change

Several behaviour change techniques (BCTs) are particularly relevant to enhancing in-situ accessibility of goals. One of them is goal setting, which involves setting up or agreeing on a goal and is usually supported by other BCTs such as self-monitoring and identifying discrepancies between goals and current status and developing concrete action plans to manage the discrepancies (Strecher et al., 1995). Action planning is another BCT that involves detailed planning of performance of the behaviour with specified context and dosage (duration, intensity, frequency) (Cane, Richardson, Johnston, Ladha, & Michie, 2015). The process is also known as forming an implementation intention (II) (Hagger & Luszczynska, 2014). A meta-analysis of 94 studies found consistent evidence that forming an II makes an important difference to whether people achieve their goals (Gollwitzer & Sheeran, 2006). By forming an II, the individual connects a certain goal-directed behaviour with an anticipated situation via "if-then" rules and pass the control of the behaviour over to the environment (Gollwitzer, 1999). In brief, forming an II is considered a conscious cognitive act that has automatic consequences (Eldrigde et al., 2016), possibly by enhancing the accessibility of the goal-action links at points of behaviour. II-based SB interventions typically provide participants with tips that can be easily incorporated into sedentary routines and automatically triggered by everyday events (e.g. "stand up when waiting for a bus or train"), which have proved feasible and acceptable for reducing SB in community-dwelling older adults (Matei et al., 2015; White et al., 2017).

The cognitive accessibility of goal constructs can also be manipulated via priming. Priming involves exposure to one stimulus (i.e. prime) influences a response to a subsequent stimulus, without the subject's conscious awareness of the influence (Gonnerman, Seidenberg, & Andersen, 2007; Neely, 1991; Nosek, Hawkins, & Frazier, 2011). Primes can fall into 2 categories: subliminal and supraliminal. Subliminal primes are above the sensory threshold but below the conscious perceptual threshold (i.e. the subject is unaware of the cue/prime). As for supraliminal primes, the subject can consciously perceive them but is unconscious of the effect of the prime. Goal priming works by activating the mental representation of a desired end state (i.e. a goal) that are then pursued unconsciously (Aarts & Custers, 2012; Custers & Aarts, 2010). Priming facilitates goal pursuits by enhancing the cognitive accessibility of the goal, triggering affective signals, and drawing motivational resources to the pursuit of the focal goal (Aarts, Custers, & Veltkamp, 2008; Shah & Kruglanski, 2002).

This speaks to the notion of action schema, according to which, human mentally represent actions at high levels of abstraction (e.g. schemas), according to motives or intended consequences (i.e. goal) rather than procedural intricacies (Vallacher & Wegner, 1987). Low-level actions are perceptually chunked into higher-order behavioural sequences, which once activated, discharges its behavioural units and progress fluently to completion in a ballistic fashion (Aarts & Custers, 2012). The activation of action schema is called habitual instigation, whereas the discharge of behavioural units is referred to as habitual execution (Gardner, Phillips, et al., 2016). For instance, a habit of micro-break can operate as the following: elements in the physical environment of the workplace may activate the goal of "work break", which leads to the discharge of the sequence of actions (i.e. stand up - walk to kitchen - make tea - come back) in an automated or semi-automated manner.

Neuroscientific research lends support to the unconscious process of goal pursuit by demonstrating that control of goals are associated with heightened activities in posterior parietal cortex – the motor and sensory area responsible for action preparation and execution – rather than the medial prefrontal cortex that handles conscious intentions (Frith, Blakemore, & Wolpert, 2000).

The fact that goals and actions are processed in the brain in a similar manner is related to a commonly used concept in the HCI literature – "affordance". According to Norman, the term refers to visual aspects of an object that suggests how the thing could possibly be used (Norman, 1988). This suggests human perception of an object might activate the goal concept or action schema related to the object's function. As a key for workplace intervention is to enable behaviour change with minimum disruptions to cognitive process in the Type 2 reflective system, it is worth exploiting the affordance of enchanted objects to heighten the cognitive accessibility of health promoting goals and action schemas unconsciously at points of behaviour.

2.6 Conclusion

This chapter has reviewed the broad epidemiological research on office workers' occupational SB and clarified key concepts in this area. The first half of the chapter specifies and defines the behaviour to be targeted in the PhD project, along with a discussion on the pros and cons of various interventional approaches. On one hand, it was more effective and realistic to displace occupational sitting with LPA. On the other hand, installation of sit-stand desks is costly and might induce prolonged standing. Hence, it is decided that the intervention will target a reduction in both total and prolonged **stationary** time of office workers in the workplace by promoting regular ambulatory breaks; the intervention should be portable, affordable, easy to be integrated with other strategies to constitute a multi-component intervention, while having component(s) dedicated to SB change.

The second half of the chapter suggests a wide range of potentially relevant determinants and theories that can be considered in the development of workplace SB interventions. Nevertheless, it is not clear to the author at this stage which theory to adopt as the foundation; such decision should be made after diagnosing the behaviour of interest in the local context in a systematic manner. Furthermore, the section has found a number of common constructs that are shared across theories, ranging from reflective to automatic motivational factors, and from subjective cognitive factors to external structural constraints. This calls for a unifying model of behaviour. Hence, Chapter 4 will report a behavioural diagnosis study that is guided by one of such models and that probes into all potential determinants.

Chapter Three

Digital interventions to reduce office workers' sedentary behaviours: a scoping review

3.1 Introduction

Chapter 1 of this thesis suggests the need for interventions that target sedentary behaviour (SB) reduction in office workers and the potential of novel digital technologies such as enchanted objects to advance this field. Chapter 2 suggests the value of exploiting affordance of everyday objects to intervene with sedentary habits from the perspective of modern habit theory and goal priming. This chapter reports a review conducted with the initial aim to inform the current intervention design with a synthesis of prior research on this topic, which has later expanded to a systematic scoping review published in an interdisciplinary journal (i.e. Journal of Medical Internet Research) (Huang, Benford, & Blake, 2019).

3.1.1 Background

The intersection between digital health and sedentary behaviour (SB) has attracted a lot of research interest and accumulated a large body of knowledge in recent years. As a first step in the doctoral research on exploiting novel digital technologies for the delivery of workplace SB interventions, the author wanted to review the literature on this topic in a systematic manner. This would also be in line with the Medical Research Council (MRC) recommendation (Craig et al., 2019) that a collation of existing evidence, ideally with a systematic review, should be conducted during the development phase of a complex intervention.

Systematic reviews and meta-analyses are well-established methods for evidence synthesis in healthcare research. A meta-analysis is often embedded in a systematic review, and involves the use of statistical techniques to integrate data from studies with similar designs (e.g. Randomised Controlled Trials, or RCT) to estimate an overall effect size (Moher, Liberati, Tetzlaff, & Altman, 2009). In the context of behaviour change intervention research, a meta-analysis could be conducted to assess the potential viability of specific intervention functions, behaviour change techniques or modes of delivery. Indeed, the author initially set out to do a systematic review and meta-analysis to compare the effectiveness of existing SB interventions delivered with screen-based versus non-screen-based embedded media.

However, a systematic review was deemed infeasible during the search process. First, the evidence was highly heterogeneous in terms of study designs and disciplines, making insufficient data for systematic analysis or meta-analysis. In addition, what the research field really lacked, was an overview of the range and nature of research conducted on this topic so far, and an assessment of the extent to which digital SB interventions have exploited the full range of technological possibilities. Therefore, the author opted for the scoping review approach, which is a form of literature review that follows a systematic search process but considers evidence from heterogeneous sources and addresses topics much broader than a systematic review does. A scoping review can be used to map evidence on a topic and identify main concepts, theories, sources, and knowledge gaps (The Joanna Briggs Institute, 2015; Tricco et al., 2018). The JBI methodology for scoping review (The Joanna Briggs Institute, 2015) and PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) (Tricco et al., 2018) checklists were followed in conducting and reporting this review,.

The remainder of the chapter will be reported with the following structure. As 7 systematic reviews have been published on interventions aimed to reduce adults' SB, the next subsections will summarise which aspects of the topic have been addressed in those reviews and why the current scoping review will make a unique contribution. Second, considering the complexity of this topic, the author will then describe existing classifications and frameworks proposed from several disciplines to describe digital technologies for behaviour change. After that, the search and review method will be introduced. The result section will start with a quantitative summary of studies and interventions identified in this review, followed by a narrative summary of design-related research conducted under each type of technological configurations. The chapter ends with a discussion of findings and implications for research in this field, as well as for this doctoral research.

3.1.2 Previous reviews

All 7 prior systematic reviews on this topic were inclusive of SB reduction interventions regardless of the presence of digital elements (Chau et al., 2010; Chu et al., 2016; Commissaris et al., 2016; Gardner, Phillips, et al., 2016; Martin et al., 2015; Prince et al., 2014; Shrestha et al., 2015).

Chau and colleagues (Chau et al., 2010) reviewed workplace studies published up to April 2009 and identified only 6 eligible studies that included sitting as an outcome measure. Only 2 types of digital media were covered (emails (Gilson et al., 2009; Marshall et al., 2003; Plotnikoff, Mccargar, Wilson, & Loucaides, 2005) and pedometer (Gilson et al., 2009)). Measurement of SB was self-reported in all 6 studies, none of which found significant intervention effect on sitting reduction. The result was inconclusive with respect to the most appropriate intervention approach or delivery mode because of disparate study designs and delivery modes across studies. With a similar inclusion criteria as Chau and colleagues' (Chau et al., 2010), a more recent review (Shrestha et al., 2015) by Shrestha and colleagues identified 20 eligible workplace studies published up to June 2015. The analysis was focused on comparing the effects of different intervention components with absence of these components or alternative components. Only a small part of the analysis was pertinent to digital interventions. First, it compared the effect of computer prompts plus information counselling on sitting reduction with information counselling only, based on data from 3 studies (Evans et al., 2012; Pedersen, Cooley, & Mainsbridge, 2014; Swartz et al., 2014)). Second, it compared the effect of different contents in e-newsletters on sitting reduction, based on one study (Gordon, 2013). The findings from both analyses were non-significant or inconclusive given the low quality of evidence. Commissaris and colleagues (Commissaris et al., 2016) specifically reviewed workplace SB interventions aimed to influence workers' SB while doing productive work. As a small part of their analyses, the authors compared 6 interventions that included self-monitoring of SB/physical activities (PA) using devices like pedometers with 4 intervention that did not include self-monitoring; the findings suggested that self-monitoring seemed to be ineffective in improving SB/PA at work. Another review of workplace SB interventions by Chu and colleagues (Chu et al., 2016) included 26 studies published up to December 2015 and classified them based on intervention strategies into 3 categories: (i.) environmental strategies, (ii.) educational/ behavioural strategies (involving educational programme and point-of-choice motivational signs) and (iii.)

combined strategies. They concluded from subgroup analyses that interventions combining multiple components resulted in the greatest sitting reduction, followed by environmental strategies. However, the review did not distinguish digital and non-digital delivery of intervention strategies within each category. Like Chu and colleagues' review (Chu et al., 2016), Gardener and colleagues' review (Gardner, Smith, Lorencatto, Hamer, & Biddle, 2016) was also focused on intervention strategies, but with a broader scope (ie. including non-workplace studies) and a more fine-grained coding scheme based on the underlying intervention functions (Michie, van Stralen, & West, 2011) and behaviour change techniques (BCTs) (Michie et al., 2013). Their findings suggest the promise of interventions based on environmental restructuring, persuasion, or education and employing BCTs such as self-monitoring, problem solving, and restructuring the social or physical environment in SB reduction. Martin and colleagues' review (Martin et al., 2015) was also inclusive of non-workplace interventions. It was suggested that interventions targeting SB only and lifestyle change may be more promising than those targeting PA only or a combination of PA and SB, which was similar to the conclusion reached in Prince and colleagues' review (Prince et al., 2014).

While shedding light on intervention strategies and components effective for reducing workplace SB, those reviews fell short in 2 aspects.

First, they did not differentiate diverse ways an intervention strategy/component could be digitally implemented and delivered. For instance, for the same strategy of point-of-choice prompts, the actual quantities of prompts received and noticed by participants may differ significantly depending on whether the break reminder was delivered on workstation screens, by smartphone notifications, or via tactile feedback from wearable devices. Apart from specific technological features, how different features were applied in combination and in support of each other is also worthy of attention. For instance, just-in-time adaptive intervention (JITAI), an approach that employs context-aware sensing and computing to detect the behavioural context and tailor the intervention in real time, can address the dynamically changing needs of individuals much better than a traditional intervention delivering static content with a fixed schedule (Nahum-shani et al., 2014). Knowledge of such nuances in technological design is important as they may lead to considerable difference in the quality and quantity of interventions delivered to participants, making outcomes incomparable across studies.

Second, none of the above reviews included the engineering and computer science literature, despite the rapid prototyping and piloting of novel technologies within these fields that may become or inform the next generation of digital interventions. An exploratory search of this body of literature has found an abundance of user-centred design research (Maguire, 2001) on technologies targeting SB reduction in office workers. Those studies, while employing very different study designs from clinical trials, have gathered valuable data about design-related outcomes (technological feasibility, usability, acceptability) usually by involving stakeholders from the outset of intervention development. The findings do not only inform technology design but also give an indication of the potential user uptake, attitude and adherence to different intervention technologies should they be moved to later stages of development and evaluation. As yet, awareness of the size and location of this body of evidence is lacking.

3.1.3 Questions and aims of the current review

In summary, while previous reviews have touched on the technological design, or the mode of delivery, for digital SB interventions, there is a need for a review that is dedicated to this topic and that encompasses a wider range of literature. Specifically, the following questions can be explored:

1. What technological designs have been applied to address the issue of office workers' SB at work?
2. What research has been done and what we can learn from them in terms of technological design for SB change in office workers?
3. Where does the research gap and opportunities lie as to utilising and innovating digital technologies to reduce office workers' SB?

The aim of this scoping review is no longer to estimate the efficacy of interventions with or without certain digital components, which should be addressed by further systematic reviews once the technological landscape is laid out. Neither is this review focused on comparing the capabilities and limitations of various brands of technological devices, which have been featured in other work (Rosenberger, Buman, Haskell, McConnell, & Carstensen, 2016; Sanders et al., 2016).

Instead, the main objective here is to scope research on digital workplace SB interventions across different disciplines, through coding of technological designs employed in interventions and mapping of research activities (e.g. design-led research, feasibility studies, randomised controlled trials) onto different stages under the MRC framework for complex intervention development and evaluation. Another objective is to synthesise the design-related findings (e.g. satisfaction, usability, acceptability, feasibility, engagement) of digital interventions and to draw implications from design and development research, which were overlooked in previous reviews.

3.1.4 Existing frameworks and classifications for digital health technologies

The technological aspect of digital health has been discussed under several umbrella terms, such as persuasive technology/system (Fogg, 1999; Oinas-Kukkonen & Harjumaa, 2009), behavioural intervention technology (BIT) (Mohr, Schueller, Montague, Burns, & Rashidi, 2014), and mode of delivery (MoD) for behaviour change interventions (Webb et al., 2010).

According to Fogg (Fogg, 1999), there are 3 general roles a persuasive technology can play in its interaction with the user, namely a tool that increases user abilities, a medium that delivers content to create experience, and a social actor that evokes social responses especially with animate characteristics.

More recently, detailed system functionalities have been identified that explicitly or implicitly support those roles. For instance, the persuasive system design model (Oinas-Kukkonen & Harjumaa, 2009) suggests design principles under the following 4 categories: (i) primary task support, which includes reducing complex behaviours into simpler ones, tunnelling experience, tailoring and personalization, self-monitoring, simulation, and rehearsal, (ii) dialogue support, including positive reinforcement, reminders, suggestions, similarity, liking, social role (iii) credibility, including expertise, authority and trustworthiness (iv) social support, by mediating social interactions and social influences. Some of these principles correspond to functional roles in the Functional Triad. For example, the principle of "reduction" (i.e. reducing complex behaviour into simple tasks helps users perform the target behaviour) and "self-monitoring" (i.e. providing means for users to track their performance or status) both enable the system to play the role of a tool. The principle of "simulation" (i.e. enable users to observe immediately the link between cause and effect) and 'social facilitation' (i.e. providing means for discerning other users who are performing the same behaviour) support the role of a medium; the principle of "social role" (i.e. adopt a virtual social role) can be directly mapped onto the role of a social actor in the Functional Triad. It should be noted that while the persuasive system design model has the merit of supporting requirement engineering, it does not follow a clear hierarchical structure and the design principles are a combination of behaviour change strategies (e.g. self-monitoring), functional elements (e.g. reminders) and non-functional characteristics (e.g. similarity, credibility).

Webb and colleagues (Webb et al., 2010) developed a novel scheme to code modes of delivering Internet-based health behaviour change interventions into 3 broad categories: (i) automated functions, including the use of an enriched information environment, automated tailored feedback on progress, automated follow-up reminders and tips, (ii) communicative functions, including mediating communication with advisors and peers, and (iii) use of supplementary modes. Similar concepts were termed as BIT elements by (Mohr et al., 2014), referring to actual technical instantiations in the intervention which the user interacts with. In addition to those functional components included in Webb's coding scheme, Mohr and colleagues (Mohr et al., 2014) listed BIT elements appearing in more recent applications, such as passive data collection (i.e. data collected with smartphone sensors or external devices or through application programming interfaces (APIs) from other available sources) and logs (i.e. data entry field facilitating self-monitoring).

All the above frameworks will be considered with adaptations wherever necessary in the analysis of the technological aspects of interventions to be reviewed.

3.2 Method

3.2.1 Search and selection

An interdisciplinary literature search was conducted of several databases (Table 1). Synonyms and subject headings relating to the following terms were applied in various combinations: *office worker, sedentary behaviour, technology, workplace* (See Table 2 for example search strategies).

Reference lists of existing reviews (Chau et al., 2010; Chu et al., 2016; Commissaris et al., 2016; Gardner, Phillips, et al., 2016; Martin et al., 2015; Prince et al., 2014; Shrestha et al., 2015) on workplace SB/PA interventions were hand searched to identify additional eligible studies. The most recent search for primary research was executed in Ovid MEDLINE on April 19th 2017, in Engineering index Compendex and Association for Computing Machinery Digital Library on July 30th 2017 and in Scopus on October 30th 2017. Auto-alerts for latest indexed articles were emailed to the author every week and checked to update the records until March 25th 2018.

Table 1 Databases searched in each research field

Fields	Databases
Medical and health sciences	Ovid MEDLINE, Cochrane Library, JBI (The Joanna Briggs Institute) Database of Systematic Reviews
Computing and engineering	Association for Computing Machinery Digital Library, Engineering index Compendex
Interdisciplinary	Scopus

Table 2 Example search strategies

MEDLINE Search Strategy

#	search term	fields searched	notes for each search	hits
1	exp Internet/ or exp Computers, Handheld/ or exp Telemedicine/ or exp Cell Phones/	subject headings	different digital media	93,517
2	exp Monitoring, Physiologic/ or exp Monitoring, Ambulatory/ or exp accelerometry	subject headings	monitoring techniques	158,104
3	(((mobile or smart or cell) adj2 (app or phone* or telephone* or technolog*)) or pedometer* or accelerometer* or Bluetooth or wireless or ((digital or connected) adj2 (health)) or (mhealth) or (ehealth) or ((information* or digital) adj3 (technolog* or media))or (software) or ((computer* or screen?) adj2 prompt*) or(email*) or(website*)).mp.	keyword	different digital media, devices and applications	55,007
4	#1 or #2 or #3		**involving digital tech**	284,380
5	(sedentary or sitting or screen time or computer time).mp.	keyword	**involving SB or related behaviours**	44,890
6	#4 and #5		tech for SB	3,811
7	("office work*" or white-collar or worksite* or workplace* or occupational health).mp.	keyword	**focused on office workers or workplace context**	46,988
8	#6 and #7		tech used on office workers for SB-related purposes	140
9	(jitai or "just in time adaptive intervention").mp.	keyword		18
10	#8 or #9		include JITAI	156
11	limit 10 to (yr="2000 - 2017" and english)		published in 2000 - 2017, and in English	152

Ei Compendex Search Strategy

#	search term	fields searched	notes for each search	hits
1	(($digital $media OR $Internet OR $web OR $smartphone OR $wearable OR acceleromet* OR $pedometer OR Bluetooth OR $wireless OR $intelligent OR $sensor OR $sensing OR $computing OR {m-health} OR {e-health} OR $software OR {internet of thing} OR {IoT}) WN KY)	title/abstract/key	**involving digital tech**	5,761,508
2	(((reduce OR increase OR decrease OR improve OR change OR modify OR modify OR encourage OR discourage OR motivate OR persuade OR prompt OR remind OR mitigate OR manipulate) AND ($sedentary OR $inactivity OR $sitting OR {computer work} OR {office work} OR {desk work} OR $break)) WN KY)	title/abstract/key	**changing SB or related behaviours**	47,677
3	({office worker} OR {working age} OR workplace* OR worksite* OR employee* OR adult* NOT teenag* NOT child* NOT $elderly NOT adolescen* NOT student*)WN KY	title/abstract/key	**involving office workers or related populations**	86,750
4	#1 AND #2 AND # 3		tech for changing SB or related behaviours in office workers or related populations	164
5	#4 NOT ((1998 OR 1997 OR 1995 OR 1993 OR 1992 OR 1986 OR 1976) WN YR) AND({english} WN LA)	years and languo	published in 2000 - 2017, and in English	155

Scopus search strategy

#	search term	fields searched	notes for each search	hits
1	TITLE-ABS-KEY (("digital medi*" OR internet OR web OR smartphone OR wearable OR acceleromet* OR pedometer OR Bluetooth OR wireless OR intelligent OR sensor OR sensing OR computing OR "m-health" OR "e-health" OR software OR "internet of thing" OR "IoT"))	title/abstract/key word	**involving digital tech**	4,054,597
2	TITLE-ABS-KEY((reduce OR increase OR decrease OR improve OR change OR modify OR modify OR encourage OR discourage OR motivate OR persuade OR prompt OR remind OR mitigate OR manipulate OR "break up") W/1 (sedentary OR inactivity OR sitting OR "computer work" OR "office work" OR "desk work"))	title/abstract/key word	**changing SB or related behaviours**	1,768
3	TITLE-ABS-KEY("office work*" OR "working age" OR workplace* OR worksite* OR employee* OR adult* AND NOT teenag* AND NOT child* AND NOT adolescen* AND NOT student*)		**involving office workers or related populations**	5,629,832
4	#1 AND #2 AND #3		tech for changing SB or related behaviours in office workers or related populations	153
5	#4 AND NOT INDEX(medline)		excluding MEDLINE indexed	53
6	#5 AND (LIMIT-TO (LANGUAGE , "English")) AND PUBYEAR > 1999 AND PUBYEAR < 2018		published in 2000 - 2017, and in English	51

ACM Digital Library search terms

#	search term	fields searched	notes for each search	hits
1	sedentary sitting break) AND acmdlTitle:(combat persuade remind change reduce increase motivate intervention)	full-text and abstr	simple search of articles on changing SB or related behaviours	102
2	filter: {"publicationYear":{ "gte":2000, "lte":2017}}		published in 2000 - 2017	85

Title, abstracts and full text of retrieved articles were reviewed for eligibility by applying the following criteria: (i) having office workers in the study sample; (ii) targeting SB during work or had proxy measures of workplace SB (objective and/or self-report daily sitting of office workers); (iii) involving digital technologies, such as mobile and computer applications, digital multimedia contents, wearable activity trackers, and other devices with sensing and computing capabilities in the production, delivery and/or customization of intervention contents; (iv) published in peer-reviewed scientific journals/conference proceedings between 2000 and 2017; and (v) in the English language.

Observational studies without administering or developing any intervention were excluded, though design research with an explicit intent to inform the development of digital SB interventions was included. Studies were also excluded if digital technologies were only used for purposes other than intervention delivery, such as using digital tools for pre- and post-study assessments without feeding the data into the intervention content in any way.

3.2.2 Data extraction

Full articles of eligible studies were reviewed to extract the following information where possible: publication data (authors, years, countries where the study was conducted, or where the first author was based if the study country was not specified, source), primary target behaviour (SB vs. PA vs. others), intervention details, study details (e.g. study type, participants, data collection methods and duration), intervention development and research phase, technological features and configurations, and outcomes. Emphasis was placed on 2 types of outcomes pertinent to the design and use of technology: design-related outcomes informative for improving intervention designs, such as satisfaction, usability, technical and process feasibility (e.g. reach, dose, fidelity of delivery), acceptability, engagement and interactions with the technology; user-related outcomes such as change in SB, PA, work performance and perceived enablers for changes.

The author categorised the whole or sections in the articles into research phases based on the following definition and criteria adapted from the MRC framework (Craig et al., 2019). The interventions were also labelled with research phase based on the category of the latest publication about the intervention.

- **Development phase:** studies could be one of the following: (1) reporting the design and development process of the intervention, following approaches such as Intervention Mapping, participatory design workshops and formative user research, (2) laboratory studies investigating design-related outcomes (feasibility, usability, and user experience) before the intervention has reached a deployable state of development, and (3) short in-the-wild deployment studies evaluating specific intervention components within a functional prototype before investing in further development.
- **Piloting/feasibility phase:** studies focused on investigating design-related outcomes of an intervention after it has reached a relatively complete stage of development, where user-related outcomes (behaviour change, health and wellbeing, productivity) were often measured as secondary outcomes with smaller sample sizes and less rigorous study designs.
- **Evaluation phase:** studies using larger sample size and more rigorous study designs to assess important user-related outcomes and establish the efficacy of interventions.
- **Implementation phase:** the intervention has already gone through the evaluation phase, and has been used in practice for some time (e.g. >= 2 years). As many implementation efforts are not reported, it was expected that this phase would have low representation.

As for the technological aspect of each intervention, existing classification frameworks were adapted to develop a technology coding scheme (Table 3). The framework was primarily based on the BIT model (Mohr et al., 2014), complemented with elements from other coding schemes/frameworks introduced previously, to cover a broader range of technologies and to reflect the speciality of the workplace setting (e.g. the addition of "mediated organisational support and social influences". Each code in the classification system can be viewed as a distinct technological feature (e.g. a data log) implemented to deliver one or more intervention component (e.g. self-monitoring of behaviours). A series of codes joined by "&" were used to annotate a technological configuration where several features were integrated to deliver one or more intervention component. For instance, an intervention that offered tailored feedback on progress based on users' self-report daily step counts was annotated with "DL & ATF". Notably, "*Scheduled prompts*" (SP) delivered according to real-time user status passively captured by sensing technologies (PDC & SP) are different from SPs that interrupt users at fixed times throughout the day regardless of the user's actual sitting time; hence, an additional code of 'JITAI' was used to annotate PDC & SP configurations to highlight the fact that the JITAI (Just-in-Time Adaptive Intervention) approach was employed in the design.

Table 3 Links between the author's codes and those from existing frameworks

Codes with descriptions	BIT elements (Mohr et al., 2014)	Roles in Functional Triad (Fogg, 1998)	MoD for Internet-based interventions (Webb et al., 2010)
Digital logs (DL): technology provides a convenient way for the user to enter data, which can be a mobile phone diary for self-monitoring of behaviours or a web-based questionnaire assessing current behaviour and psychological determinants of behaviours	Log	Tools	Not applicable (these are considered BCTs rather than MoD in the conceptual framework)
Passive data collection (PDC): use wearable, smartphone-based and environment-based objective monitors to obtain time-stamped SB records automatically	Passive data collection		
Connected device (CD): one or more external sensing device is connected either wirelessly or with a cable to a central computing device	Not applicable		
Scheduled prompts (SP): break reminders delivered either at fixed intervals or with some schedule adaptive to the real-time user status	Notification push	Tools/medium/ social actor	**Automated functions:** automated follow-up messages (e.g. reminders, tips, newsletters), automated tailored feedback based on individual progress (e.g. comparison to goals or norms, reinforcing messages or coping strategies), use of enriched information environment (newsletters, tips)
Information delivery (ID): one or more forms of digital media with varying richness (text, links, testimonials, videos, or games) is used to present information that is usually static over time (e.g. health facts, scripted motivational messages and practical suggestions)	Information delivery	Medium/ social actor	
Automated tailored feedback (ATF): feedback on individual behaviours and progress, such as personalised goal setting and recommendations, that usually require some calculations of data input from DL or PDC	Reports, visualisation	Medium/ social actor	
Mediated organisational support and social influences (MOSSI): create an online environment for social interactions and influences, such as emails conveying managers' approval and online forums facilitating communication and/or competition among programme participants; email access to consultant/coach support should be coded under Information delivery instead.	Messaging	Medium	**Communicative functions:** access to peer-to-peer support

3.2.3 Data synthesis

Results on study characteristics (i.e. publication data, study design, MRC development and research phase, participants) and intervention characteristics (i.e. target behaviour, theoretical underpinning, technological design, MRC development and research phase) were quantitatively summarised and presented using descriptive statistics. The technological landscape was mapped in the format of a crosstab, where each row was dedicated to a technological feature or configuration, and each column represented one of the 4 MRC development phases; row percentage was calculated to indicate the proportions of interventions reaching a certain development phase under each technological design category.

Because of the heterogeneity of study design (e.g. interviews, lab testing, RCTs) and outcomes (e.g. design inspirations, usability, engagement, effectiveness), meta-analysis of specific outcomes across studies was not suitable. Instead, the author narratively summarised findings under each category of technological configuration, with a focus on design-related findings and implications.

3.3 Results

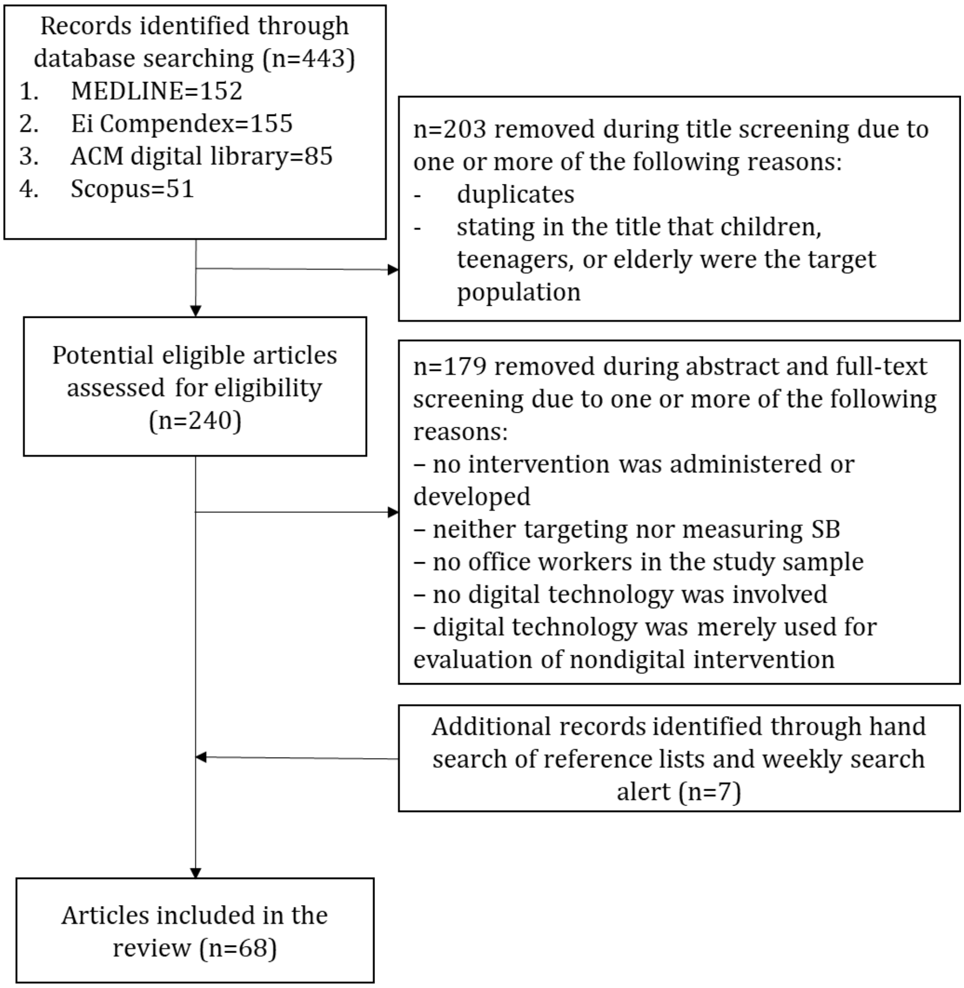

Figure 7 Search and screening results

A total of 68 articles were included in this review (Figure 7), corresponding to 45 unique interventions. Each article was counted as a separate study, even it was focused on a different aspect of the same research project reported in another article. The details of all included studies and interventions can be found in Appendix 1.

3.3.1 Study Characteristics

3.3.1.1 Publication data

As shown in Figure 8, there is an overall upward trend in the number of articles published on this topic over the past two decades or so, with 2014 being the most fruitful year. The 64 published articles represented research that was conducted in 16 countries, in addition to 2 articles that reported international studies conducted in 64 countries (Ganesan et al., 2016) and 3 countries (the UK, Australia and Spain) (Gilson et al., 2009) respectively. The most represented countries were Australia (n=19 articles), the US (n=17), the Netherlands (n=8) and the UK (n=4). Another 7 European countries (e.g. Austria, Spain, Portugal, Belgium, Germany, Switzerland, Finland) were represented in a total of 20 articles.

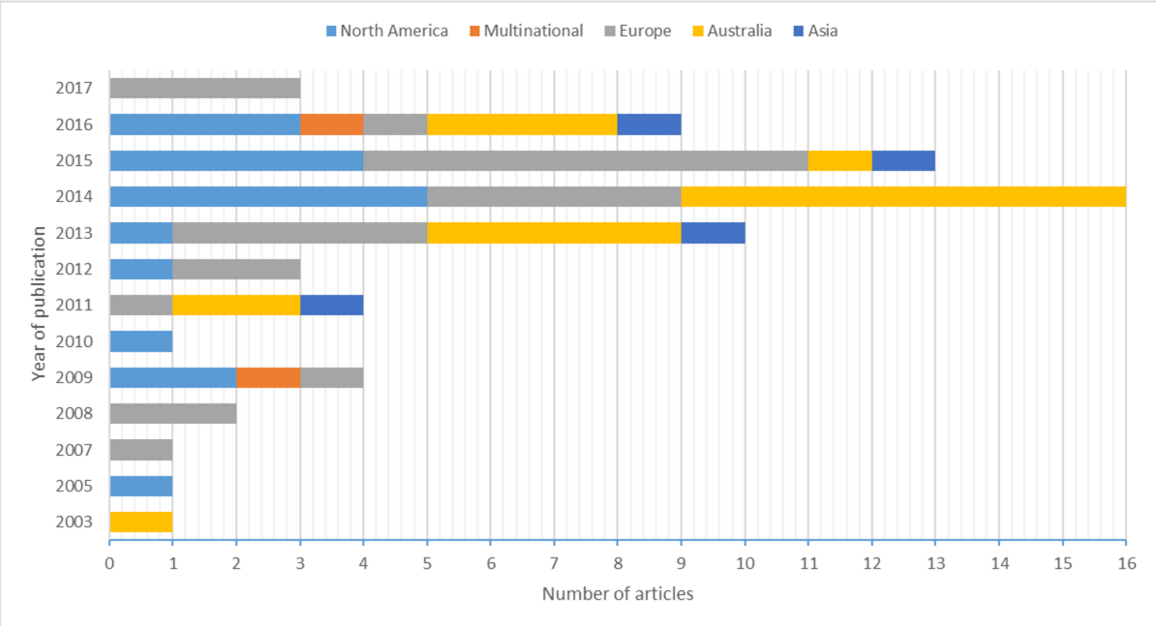

Figure 8 Number of articles by year of publication and country of study

In terms of publication avenues, the included articles were published in 40 different scientific journals and proceedings. Divided by disciplines, n=42 articles were published in the field of medical and health sciences, n=13 in engineering and computing (including ergonomics and human factors), and n=13 in interdisciplinary journals/conferences (e.g. PloS One), out of which n=6 were in the interdisciplinary field of digital health (e.g. Journal of Medical Internet Research).

3.3.1.2 Study design

For experimental studies, n=25 articles reported randomised controlled trials (RCTs; including cluster RCTs), n=4 reported randomised crossover studies, n=4 reported before-and-after studies with control/comparison group(s), n=10 reported before-and-after studies without control or comparison group(s). In addition to those traditional experimental designs, n=9 articles reported descriptive quantitative process data (e.g. fidelity of delivery, reach, usage pattern of the technology, and compliance to intervention from survey and interaction data etc.), n=11 articles reported qualitative data reflecting participants/stakeholders' perspectives (e.g. interviews, focus groups), and n=19 articles reported the design and development of the technology.

Note the above categories were not mutually exclusive as one article could include both quantitative and qualitative results, and reported both formative and evaluative studies.

3.3.1.3 Development and research phase

All 58 articles featured complex interventions according to the MRC definition. Table 4 shows the number of articles categorised to each intervention development phase based on the MRC framework. Except for 2 articles that reported both the development and piloting phase (Rabbi, Pfammatter, Zhang, Spring, & Choudhury, 2015; Van Dantzig, Geleijnse, & Van Halteren, 2013), each article was assigned one category.

Table 4 Distribution of articles by development and research phases

Phase under the MRC framework	Number of articles
Development	19
Piloting/feasibility	34
Evaluation	10
Implementation	7

3.3.1.4 Participants

All studies included participants employed in office-based jobs. Indeed, most studies recruited participants from office-based workplaces covering different sectors and worksite sizes, although the majority of studies were conducted in universities and public-sector worksites. Only a few design and development studies recruited participants via local newspaper, social media and from subject pools, resulting in a mixture of office workers and unemployed participants (e.g. (Rabbi et al., 2015) – 13 students and 4 office workers; (Bond et al., 2014; Thomas & Bond, 2015) – 12 retired/employed and 18 office workers; (Mukhtar & Belaid, 2013) – 2 graduate students and 2 faculty members; (He & Agu, 2014) – 6 students and 2 colleagues).

A total of 63 studies recruited participants regardless of BMI, whereas 5 studies targeted overweight and obese adults (Bond et al., 2014; Carr, Karvinen, Peavler, Smith, & Cangelosi, 2013; Gilson et al., 2016; Júdice, Hamilton, Sardinha, & Silva, 2015; Thomas & Bond, 2015); all studies but 1 (Green, Sigurdsson, & Wilder, 2016) included both female and male participants. Except for 1 design and development study where sample size was not reported, sample sizes ranged from 1 (Jafarinaimi et al., 2005) to 91 (Coffeng et al., 2012) among development studies, 3 (Green et al., 2016) to 412 (Coffeng et al., 2014) among piloting studies, 153 (C. L. Brakenridge et al., 2016) to 631 (Sternfeld et al., 2009) among evaluation studies, and 291 (Aittasalo et al., 2017) to 69291 (Ganesan et al., 2016) among implementation studies.

3.3.2 Intervention Characteristics

3.3.2.1 Target behaviour

Of all 45 interventions, n=18 interventions (27 articles) focused primarily on SB reduction, n=14 (22 articles) targeted a combination of SB reduction and other behaviours (e.g. PA promotion, diet management, posture correction, prompting social interactions with colleagues, general lifestyle change), n=13 (19 articles) targeted other behaviours (e.g. posture correction, PA promotion) without an SB reduction element in the intervention design but reported SB change as secondary behavioural outcome.

3.3.2.2 Theoretical underpinning

N=19 interventions were underpinned by theories, which included theory of planned behaviour (TPB) (n=5), social cognitive theory (n=4), social ecological model (n=4), the stages of change/transtheoretical model (n=4 interventions) and theories of habits (n=3). The development of n=3 interventions followed frameworks (e.g. Intervention Mapping) that supported theory-based intervention design (Coffeng et al., 2012; Neuhaus, Healy, Fjeldsoe, et al., 2014; van Berkel, Proper, Boot, Bongers, & van der Beek, 2011).

3.3.2.3 Technological design and development phase

Appendix 1 details the technological designs of included interventions, study details and findings. Table 5 presents summative results on different technological features/configurations in relation to the development and research phase based on MRC framework.

Table 5 Summative results on technological design and development phase

Technological design	Total, n (%)	Development, n (%)	Feasibility/piloting, n (%)	Evaluation, n (%)	Implementation, n (%)
Overall	45 (100)	13 (29)	21 (47)	8 (18)	3 (7)
ID[a]	36 (100)	9 (25)	17 (47)	8 (22)	2 (6)
DL[b]	14 (100)	1 (7)	5 (36)	5 (36)	3 (21)
PDC[c]	39 (100)	12 (31)	18 (46)	6 (15)	3 (8)
CD[d]	12 (100)	6 (50)	5 (42)	1 (8)	—[e]
SP[f]	28 (100)	13 (46)	14 (50)	1 (4)	—
ATF[g]	29 (100)	9 (31)	12 (41)	6 (21)	2 (7)
MOSSI	14 (100)	2 (14)	4 (29)	6 (43)	2 (24)
MOSSI[h] & ID	12 (100)	1 (8)	3 (25)	6 (50)	2 (17)
PDC & ATF	26 (100)	9 (35)	11 (42)	4 (15)	2 (8)
PDC & SP (JITAI[i])	19 (100)	13 (68)	5 (26)	1 (5)	—
Using on-board sensors	8 (100)	6 (75)	2 (59)	—	—
Using connected sensing devices (CD & PDC & SP	11 (100)	7 (64)	3 (27)	1 (9)	—

[a]ID: information delivery; [b]DL: digital log; [c]PDC: passive data collection.; [d]CD: connected device; [e]—: no intervention found in the category; [f]SP: scheduled prompts; [g]ATF: automated tailored feedback; [h]MOSSI: mediated organizational support and social influences; [i]JITAI: just-in-time adaptive interventions.

3.3.3 Summary of Design-Related Findings

3.3.3.1 Information delivery & mediated organisational support and social influences

The use of digital media for *'information delivery'* was prevalent among reviewed interventions and was sometimes integrated with the feature of "*mediated organisational support and social influences*" ("ID & MOSSI"). A long-standing use case of this was motivational messages sent from managers' e-mail addresses, to convey organisational support and endorsement for the programme (Brakenridge et al., 2016; Gilson, McKenna, Cooke, & Brown, 2007; Healy et al., 2013; Neuhaus et al., 2014). In other cases, ID & MOSSI was implemented in the form of online discussion forums or social networking sites to encourage individuals to share experiences with peers, and to foster social support or team competition (Aittasalo et al., 2017; Carroll et al., 2013; Ganesan et al., 2016; Puig-Ribera et al., 2015; Sternfeld et al., 2009).

2 thirds of the ID & MOSSI interventions had moved beyond development and piloting phases, with 6 interventions (Brakenridge et al., 2016; Gilson et al., 2009; Healy et al., 2016; Puig-Ribera et al., 2017; Sternfeld et al., 2009; van Berkel, Boot, Proper, Bongers, & van der Beek, 2014) having reached the evaluation phase, and 2 (Aittasalo et al., 2017; Ganesan et al., 2016) the implementation phase. There was consistent evidence for positive user-related outcomes (e.g. reduction in SB, increase in PA and work productivity) across studies (Brakenridge et al., 2016; Gilson et al., 2009; Healy et al., 2016; Puig-Ribera et al., 2017, 2015; Sternfeld et al., 2009), except for 1 study (van Berkel et al., 2014), where a lifestyle intervention with a small SB intervention component was found to yield nonsignificant intervention effects on SB or other lifestyle behaviours.

The only published development work on ID & MOSSI configuration was novel in applying ambient and affective interfaces to persuasion. A system called "PerFrame" was created to play footages of the user's close friend performing expressions showing either approval or disapproval, depending on whether the user's behaviour was healthy or not (Obermair, Reitberger, Meschtscherjakov, Lankes, & Tscheligi, 2008).

3.3.3.2 Digital Log & Automated Tailored Feedback

Integration of "*digital log*" and "*automated tailored feedback*" was another common configuration ("DL & ATF"), as such systems took user inputs and generated feedback accordingly. These ranged from textual advice tailored to psychological constructs assessed with a simple web-based questionnaire (Compernolle et al., 2015; De Cocker, De Bourdeaudhuij, Cardon, & Vandelanotte, 2015; Marshall et al., 2003) to sophisticated visualisation and simulations tools providing feedback on outcomes of self-report behaviours, such as daily step counts (Ganesan et al., 2016; Puig-Ribera et al., 2015; Sternfeld et al., 2009) and physical activities (PA) (Cooley & Pedersen, 2013; Mainsbridge, Cooley, Fraser, & Pedersen, 2014).

Although only 8 interventions were identified in this category, half of them (Compernolle et al., 2015; Marshall et al., 2003; Puig-Ribera et al., 2015; Sternfeld et al., 2009) had reached the evaluation phase and 1 (Ganesan et al., 2016) the implementation phase. All report SB reduction in the intervention group over time though only 2 studies (Puig-Ribera et al., 2015; Sternfeld et al., 2009) reported significant between-group (intervention vs. control) difference in SB reduction.

Several studies have examined design-related outcomes such as user engagement and experience of the DL & ATF platform. For instance, it was reported in (Compernolle et al., 2015) that 86% of the participants in the intervention condition requested computer-tailored feedback and advice, and that the majority rated the advice positively; in contrast, in (Marshall et al., 2003), only half of the participants visited the website for tailored feedback and even fewer used the website for a second time. While both platforms delivered stage-based advice tailored to participants' self-report PA and psychological determinants of PA, it could be the provision of pedometers in (Compernolle et al., 2015) that made a difference.

Despite a lack of evidence showing DL & ATF as the efficacious component causing SB reduction, it was reported as a key enabler of behaviour change in several qualitative studies. Participants in (Bort-Roig et al., 2014) highlighted the motivational value of being able to view logged data through visual graphics in a website and gain feedback; (Cooley et al., 2014) interviewed 15 participants, who suggested that the mere act of logging non-purposeful physical activities during breaks changed their perceptions of what constituted exercise - they also thought the automated feedback on progress helped them set up goals.

3.3.3.3 Passive Data Collection & Automated Tailored Feedback

Replacing *"digital log"* with *"Passive data collection"* to provide input for *"automated tailored feedback"* is a more technologically advanced configuration ("PDC & ATF"), as it capitalises on automated sensing technologies and activity detection algorithms. Smartphones and pedometers were the 2 most frequently used devices for this configuration.

A number of smartphone applications incorporated data from on-board accelerometers or utilised Android APIs (Application Programming Interface) for real-time activity classification. Feedback was usually offered in the form of a dashboard with a break timer, daily accumulative active and inactive minutes, and/or a lifelog of activity episodes in chronological order (Bond et al., 2014; He & Agu, 2014; Mukhtar & Belaid, 2013; Van Dantzig et al., 2013). Practical issues with this technological approach were identified, such as "phone battery drained quickly because of the accelerometer use" and "users did not always carry the phone with them" (He & Agu, 2014; Van Dantzig et al., 2013; Wadhwa et al., 2015).

Like in one of the aforementioned studies (Compernolle et al., 2015), pedometers were often used to provide instant and simplistic feedback on PA. They were also used as a support tool (i) alongside DL to enhance the accuracy of self-report PA, and (ii) alongside MOSSI to provide the metric for team-based competition (Carr et al., 2013; Ganesan et al., 2016; Gilson et al., 2007; Júdice et al., 2015; MacNiven, Engelen, Kacen, & Bauman, 2015; Parry et al., 2013; Puig-Ribera et al., 2017; Swartz et al., 2014). Participants generally considered the technological monitoring tool very helpful (Bort-Roig et al., 2014; Carr et al., 2013) and an evidence for organisational investment in staff health (Gilson, McKenna, & Cooke, 2008).

Notably, only 6 out of the 25 PDC & ATF had reached the evaluation and implementation phases (Brakenridge et al., 2016; Compernolle et al., 2015; Ganesan et al., 2016; Gilson et al., 2009; MacNiven et al., 2015; Puig-Ribera et al., 2015), 5 of which were pedometer-based interventions. Most interventions that used smartphone for both PDC and ATF were in the development and piloting phase.

Development research conducted in this space was innovative and informative in several aspects. First, machine learning was applied to classify activities and generate suggestions based on the user's past behavioural pattern, which were found to yield stronger intention to follow than generic suggestions (Rabbi et al., 2015). Second, the likeability of different forms of feedback was explored: 'at-a-glance' and real-time display of summative data was perceived as useful and motivating by users (Bond et al., 2014; He & Agu, 2014); potential features demanded by users were visual feedback on the health outcomes of SB, accurate and reliable data sources, and the control over the collection and sharing of their data feedback with colleagues (Mohadis & Ali, 2016)

3.3.3.4 Passive Data Collection & Scheduled Prompts

Passively collected data was utilised in 19 interventions to determine when to trigger prompts. Those were coded as "PDC & SP (JITAI)", to be differentiated from the 9 SP interventions that prompted users at fixed times throughout the day (Donath, Faude, Schefer, Roth, & Zahner, 2015; Green et al., 2016; Júdice et al., 2015; Kerr et al., 2016; Mackenzie et al., 2015; Mainsbridge et al., 2014; Taylor et al., 2016). Smartphone was the top-choice device used in this category, followed by desktop computers. A few studies used other connected devices (CD), which will be discussed in the CD & PDC & SP configuration category.

Eighteen out of 19 PDC & SP interventions were in the development and piloting phase. This body of research produced outcomes particularly relevant to this review.

First, the studies were fruitful in identifying the optimum modality, frequency and manner for interrupting users in the middle of sedentary work. Van Dantzig and colleagues (Van Dantzig et al., 2013) suggested the textual content of the persuasive messages was unimportant and a timely tactile notification on the smartphone might be just sufficient. Thomas and Bond (Thomas & Bond, 2015) conducted a randomised crossover study with audible break prompts delivered from an smartphone application for one week in each of the 3 conditions: (i) a 3-min break prompt after 30 continuous sedentary minutes; (ii) a 6-min break prompt after 60 sedentary minutes and (iii) a 12-min break prompt after 120 sedentary minutes. It was discovered that the 3- and 6-min conditions resulted in the greatest number and sum duration of walking breaks, the best and fastest adherence to prompts; from the users' perspective, the 6-min condition was the most preferred one (Bond et al., 2014). Mukhtar and Belaid (Mukhtar & Belaid, 2013) found that reminders delivered with variable intervals adaptive to the duration of the last inactive episode were preferred by users to reminders delivered with fixed intervals. In terms of manner, some interventions adopted a so-called 'passive prompt' approach, in which the screen was locked unless the user complied with the suggestions, whereas others followed an 'active prompt' approach by allowing the user to snooze or dismiss the prompt and carry on work. While higher odds of compliance were recorded in the passive prompts condition than in active prompts condition in one study (Cooley & Pedersen, 2013), user annoyance with the passive prompt approach was also reported (Cooley et al., 2014).

Second, the research was innovative in applying 'quick-and-dirty' design methods to piloting novel intervention approaches and studying potential usability issues without large investment in development. For instance, in the abovementioned PerFrame study, a so-called 'Wizard of Oz' paradigm was applied to control the system output. That is, instead of implementing complex Computer Vision algorithms, the researcher observed the user's sitting posture via a camera and remotely controlled which video footages to play (Obermair et al., 2008). In another example, researchers drew on a range of design research techniques such as diary, scenario and technology probe to elicit user feedback on the design idea of an emotionally expressive robot, which would otherwise take a long period of development before getting users' input (Reeder, Kelly, Kechavarzi, & Sabanovic, 2010).

3.3.3.5 Connected Devices & Passive Data Collection & Scheduled Prompts

Within the "PDC & SP" configuration category, 11 intervention delivery systems employed an even more technologically advanced feature, by drawing on data from externally *connected devices* (CD).

Only one CD & PDC & SP intervention had moved to the evaluation phase (Brakenridge et al., 2016). The study compared an intervention including a wearable activity tracker that made the smartphone prompts responsive to real-time user status with an intervention without the external device. There was no significant between-condition difference in prolonged sitting reduction; the wrist-worn activity tracker component was characterised by a modest uptake (70.5%) and variable self-directed use (11.6 days in the first 12 weeks, 13.8%).

The development and piloting research in this space extended our knowledge of devices and media that can be possibly used for delivering SB interventions.

A range of peripheral sensing devices with various form factors were incorporated in interventions reviewed, including cushions on chairs to monitor sitting time (Gilson et al., 2016; Jafarinaimi et al., 2005), wearables to capture activities and postures (Brakenridge et al., 2016; El-sayed, Farra, Moacdieh, & Hajj, 2011; Slootmaker, Chinapaw, Schuit, Seidell, & Van Mechelen, 2009), and sensors attached to workstations to infer sedentary time from workstation use time (Ferreira, Karapanos, Caraban, & Karapanos, 2014; Van Dantzig et al., 2013).

A number of data transfer technologies were used to establish connectivity between devices. Bluetooth technology was commonly used for wireless communications between portable devices, for instance, between an Android/iOS device and a nearby peripheral sensing device (Brakenridge et al., 2016; Carr et al., 2015). Some early studies used mobile networks to send text messages from a server to a mobile phone as a way of prompting users (Slootmaker et al., 2009; Van Dantzig et al., 2013). USB and other cable-based connections were often utilised in systems for which portability was not crucial. For instance, (Carr, Walaska, & Marcus, 2012; Ferreira et al., 2014; Slootmaker et al., 2009; Van Dantzig et al., 2013) used USB-type protocols for sending environment-based sensor data to the users' workstations, where the prompts were scheduled and delivered. USB protocol was also used in early prototypes of connected systems (Jafarinaimi et al., 2005; Mateevitsi, Reda, Leigh, & Johnson, 2014), to actuate novel user interfaces (e.g. mechanically controlled sculpture, ambient light) from an Arduino, which is an open-source electronic prototyping platform for creating interactive electronic objects.

Pros and cons of different technologies were explored. Wadhwa and colleagues (Wadhwa et al., 2015) examined the technical feasibility and social acceptability of mobile vs. environment-based sensing. The authors proposed a triggered-sensing approach to replace some mobile sensing with infrastructure sensing to extend battery life of mobile sensors; in addition, they analysed users' response latencies to different prompts and found a slight user preference for mobile-based notifications to workstation-based ones. Haller and colleagues (Haller et al., 2013) connected a posture sensing chair to 3 different types of media for delivering prompts (onscreen graphic feedback, tactile feedback from the chair itself, and 'physical feedback' delivered by a plastic plant that became droopy to represent bad posture of the user); the result was in favour of the 'physical' feedback, as it required the shortest time to return to the main task after the prompted activity and was rated by users as the least disturbing. Along the same line of reasoning, several design studies assessed the technical feasibility, ease of understanding, usability and likeability of ambient displays, such as programmable sculptures that changed shape (Ferreira et al., 2014; Jafarinaimi et al., 2005), or ambient lights that altered colour (Fortmann, Stratmann, Boll, & Poppinga, 2013; Mateevitsi et al., 2014) to reflect user's sedentary time and remind the user to take breaks. Nonetheless, while all the researchers suggested the need for longer-term experiments to establish the effectiveness of their technologies, no published follow-up studies were found.

3.4 Discussion

This chapter sought to scope evidence across disciplines on digital interventions for reducing office workers' SB, to identify research gaps in utilising and innovating digital technologies in this field, to draw implications for future work, and to synthesize design-related findings. This subsection will discuss the findings in relation to these sub-aims.

3.4.1 Mapping out the research field

The findings can, first of all, be used as a roadmap to indicate the size, variety and location of literature on this topic. A total of 68 articles describing 45 interventions were identified. While only a few studies were capable of providing definitive evidence (25 RCTs, of which only 9 were qualified as 'evaluation' phase studies), this is to be expected in an expanding field of interest with a lot of efforts to bring in novel technological features and configurations. In terms of geographic distribution, the development and piloting work conducted in this field was located across the globe, whereas evaluation and implementation research tended to be concentrated in specific countries and was usually associated with large national or international research initiatives (e.g. Australia – "Stand up Australia", "Global Corporate Challenge"; the Netherlands – "Vitality in Practice"; Spain – "Walk@WorkSpain"). Some of those projects were also fruitful in generating publications, partly because they followed a phased approach to conducting and reporting the development, piloting and evaluation of complex interventions as recommended by the MRC guidance ("Stand up Australia" – (Healy et al., 2013; Healy et al., 2016; Neuhaus, Healy, Fjeldsoe, et al., 2014; Neuhaus, Healy, Dunstan, Owen, & Eakin, 2014; Stephens et al., 2014); "Vitality in Practice" (VIP) project – (Coffeng et al., 2012; Coffeng, Hendriksen, van Mechelen, & Boot, 2013)). In terms of disciplines where research on this topic can be located, the search results demonstrate the added value of searching for articles outside medical and health sciences databases. Finally, confirming the author's observation mentioned in Chapter 2, many SB reduction elements were embedded in interventions targeting other behaviours such as posture correction or PA promotion. Indeed, only 18 interventions out of the 45 interventions identified in the present review solely targeted SB reduction.

This review also maps the technological landscape and research activities in this field, with a novel coding scheme constructed specially for coding the technological designs. As shown in Table 5, the integration of *'information delivery'* and *'mediated organisational support and social influences'* ('**ID & MOSSI**'), and that of *'digital log'* and '*automated tailored feedback'* ('**DL & ATF'**) have mostly been researched in the evaluation and implementation phase. Less investment in development or piloting was observed, probably because those configurations typically used technologies merely as media to exchange information that were traditionally delivered with print media or face-to-face communications, and hence less complex computational model or infrastructure design were needed. In contrast, research on interventions that delivered '*automated tailored feedback*' or '*scheduled prompts*' (**SP**) based on '*passive data collection*' (**PDC & ATF, PDC & SP**), in particular with sensors from connected devices (**CD & PDC & SP**), mostly remained in the development and piloting phase.

Notably, while validated PDC devices, such as the ActivPAL (PAL Technologies Ltd, Glasgow, UK) and ActiGraph (LLC, Pensacola, FL, USA), were widely used for outcome measurement (Brakenridge et al., 2016; De Cocker et al., 2016; Donath et al., 2015; Evans et al., 2012; Healy et al., 2013; Healy et al., 2016; Júdice et al., 2015; Kerr et al., 2016; Neuhaus, Healy, Dunstan, et al., 2014; Parry et al., 2013; Stephens et al., 2014; Swartz et al., 2014), they were seldom integrated with other technological features as part of the intervention delivery system in the studies reviewed. This might be because early models of the ActivPAL and ActiGraph devices are not equipped with any output module (e.g. a screen) to let wearers, or even researchers, receive feedback on SB during the monitoring period; neither are the stored data accessible to third-party applications or devices in real time for implementation of JITAI. This may in turn demotivate deployment of those devices beyond the assessment period (usually 1 week or 5 workdays), which could otherwise collect data throughout the whole study period and generate valuable insights into the process of change, as demonstrated in several studies (Stephens et al., 2014; Thomas & Bond, 2015; Van Dantzig et al., 2013). This situation should soon be improved with the latest ActiGraph GT9X Link (LLC, Pensacola, FL, USA) and SitFIT (PAL

Technologies Ltd, Glasgow, UK) devices that come with screens for instant feedback on behaviours and Bluetooth modules for communication with external devices.

This was the reason why '*Connected Devices'* (**CD**) was coded separately and considered to be a very important trend that could potentially catalyse a paradigm shift in the use of data in behaviour change. Not to mention easier integration of multiple data sources to make interventions more relevant to the context, CD greatly expands the range of interfaces and media that can be used to deliver 'Scheduled Prompts' (**SP**) to users. The review has identified exploratory work on developing and piloting ambient displays to deliver break reminders subtly (Fortmann et al., 2013; Mateevitsi et al., 2014; Obermair et al., 2008). The technological advancements in the field of Tangible, Embedded and Embodied Interactions (TEI) presents new promise for this line of research, as mechanically controlled objects have been created (Haller et al., 2013; Jafarinaimi et al., 2005) or designed (Ferreira et al., 2014; Reeder et al., 2010) as a creative and pleasant way to persuade users into taking breaks and caring for their own health.

3.4.2 Identifying research gaps

2 notable blank spots can be identified in Table 5, suggesting areas where evidence is lacking, and more investigations are warranted.

One is the dearth of research on interventions utilising connected devices (**CD**), especially in evaluation and implementation phases. Research opportunities exist in exploiting wireless connectivity to make interventions more relevant to individual users and contexts. Manufacturers of well validated PDC devices are starting to provide Software Development Kits (SDKs), like the new ActiGraph Link SDK, which allows third-party applications or devices to stream the PDC device' raw data in real time or near real time. This is very encouraging, and yet no studies have been published featuring interventions using such SDKs to exploit the value of externally connected devices. To achieve this, collaborations between health scientists, computer scientists and engineers from both academia and the industry need to be fostered.

Another notable blank spot in Table 5 is the lack of research on scheduled prompts (**SP**) beyond the feasibility/piloting phase. Considering the numerous innovative prompting installations that have been developed and piloted in engineering and computer science, efforts could be directed to moving them to the next phase of evaluation with a more rigorous study design. This line of research is promising for 2 reasons. Firstly, research suggests in-the-moment guidance that prompts smaller yet more frequent changes in existing behaviour has potential for greater impact than suggestions only tailored to overall behaviours periodically (e.g. daily energy burnt) (Rabbi et al., 2015). Yet, there is a lack of knowledge about the best manner of prompting office workers in the middle of sedentary work. Secondly, as the cost of embedded electronics is dropping, interventions featuring novel interfaces, such as those reminding users subtly by changing the ambient light or appearance of physical artefacts (Fortmann et al., 2013; Jafarinaimi et al., 2005; Mateevitsi et al., 2014), will become more affordable and hence scalable.

3.4.3 Calling for an interdisciplinary approach

Upon reflection of applying the MRC framework to map a body of interdisciplinary knowledge, the author has come to realise different perceptions of the meanings of "development" research across disciplines. There is an increasing trend in reporting the design and development of intervention contents in the field of health sciences, with encouraging examples where researchers followed through and published more than one stages of developing, piloting and evaluating an intervention (Coffeng et al., 2012; Neuhaus, Healy, Fjeldsoe, et al., 2014; van Berkel et al., 2011). However, when it comes to the user-centred design and technical development of the intervention delivery technologies, health and behavioural scientists without technical backgrounds are less likely to be involved (or at least, to report their processes). Meanwhile, although technological innovations are taking place in the fields of engineering and design, the majority of them are not guided by systematic frameworks for theory-based intervention design such as the Behaviour Change Wheel (Michie et al., 2014) or the Intervention Mapping (Eldrigde & L. K., Markham, C. M., Ruiter, R. A. C., Fernàndez, M. E., Kok, G., & Parcel, 2016). This makes it difficult to develop a theoretical understanding of why the intervention works or does not work, which has potentially prevented research from moving downstream to the evaluation phase, and prevented the study results from being utilised by scientists in other fields.

It requires more thinking as to how to better connect and empower 2 communities – the community with expertise in intervention content development and evaluation, and the community with capacities to design, develop and study technologies with users. The answer to the question is beyond the scope of this review. Nevertheless, as a starting point, researchers from all disciplines can familiarize themselves with the MRC guidance and position their research in the big picture of developing and evaluating complex interventions. It would also be valuable to follow systematic intervention development frameworks like the Behaviour Change Wheel (Michie et al., 2014) to ensure the resultant intervention has a coherent theoretical basis, a clear description of intervention content and mode of delivery, and explicit mechanisms of action, which will enable contribution to theory development. Behavioural intervention designers can also engage more with technology development research, by contributing to early-stage user requirement elicitation studies, and using findings accumulated with "quick-and-dirty" design methods, such as Wizard-of-Oz, scenario-based design, and technology probes.

3.4.4 Drawing design implications

A synthesis of design-related findings has led the author to consider the following aspects in designing the intervention and technology for the doctoral research:

1. The intervention could advantageously employ the technological feature of ATF on SB as they are highly valued and liked by participants/users in previous studies

2. The design should consider different forms of feedback and their respective purposes, ranging from a detailed lifelog of activity episodes for reflection and education, through "at-a-glance" summative data for real-time awareness of behaviour and consequences of behaviour, to a straightforward break countdown for actionable information.

3. Unlike feedback delivery, the delivery of prompts does not necessarily require rich media; the timeliness matters more than the textual content of the message; prompting the user after every 60 minutes of sitting seems most acceptable, although a variable interval adaptive to the user's past compliance to prompts would likely be more preferred by the user.

4. To support sustainable behaviour change, prompts for breaks should not annoy users; there is consistent evidence for positive user evaluations of "physical", ambient feedback (by changing the appearance of the physical environment) delivered with novel screenless media.

3.4.5 Limitations

The aim of this review was to scope the research activities and describe the technology design in SB interventions targeting office workers, as such, the author did not intend to compare or synthesize the behaviour change outcomes across interventions with meta-analysis. Future reviewers may wish to conduct meta-analyses on the viability of a specific technological design after more evidence is accumulated in the field.

In addition, the review used a single code for PDC and focused on its integration with other technological features. The measurement and self-monitoring properties of different devices used in those studies could have been coded in more detail, for instance, by deriving another coding scheme to systematically annotate properties such as wear locations, outcomes measured, and the type of feedback available. However, this was deemed unnecessary, because a scoping review specifically on devices for self-monitoring SB and PA (Sanders et al., 2016) that included a fined-grained coding of measurement attributes including but not limited to the above was published during the data extraction phase of this review.

3.5 Conclusion

This chapter presents a scoping review that demonstrates the prevalent and diverse use of digital technologies in SB interventions targeting office workers. The use of technology to deliver information, to mediate organisational support and social influences, and to provide feedback based on self-report data is well-established in this field. More research is needed to (i) exploit wireless connectivity between devices to make interventions more adaptive to the user's current state and context; and to (ii) carry forward the work on ambient, tangible and embedded media as novel modes of delivering prompts and feedback. Opportunities exist to improve the utility of future research by adopting an interdisciplinary approach and fostering interdisciplinary collaborations, potentially under the MRC framework for development and evaluation of complex interventions and systematic approaches to designing theoretically driven interventions. The recommendations can be used by researchers working in this field and will be used in the current doctoral research to inform the development, evaluation and reporting of a workplace SB intervention.

Chapter Four

Office workers' perceived determinants of occupational sitting and break behaviours: a diary-probed interview study

4.1 Introduction

It is evident from the scoping review in Chapter 3 (covering literature published up to the end of 2017) that this field suffers from a paucity of intervention developed following a systematic framework or based on a comprehensive and in-depth theoretical understanding of the behaviour. If we consider digital behaviour change interventions (DBCIs) or persuasive technology (PT) as a form of behavioural medicine delivered with digital media, just as a doctor needs to diagnose a patient's problem before writing out a prescription, intervention designers will also benefit from carrying out a thorough behavioural diagnosis prior to developing a behaviour change intervention. The key question to be answered at this stage of intervention design is – what are the underlying factors and processes that require modification, in order for office workers to break up sedentary behaviour (SB) regularly at work?

In view of the importance of behavioural diagnosis and the gap in the existing literature, the author has conducted and published one of the first COM-B behavioural diagnostic studies on office workers' sedentary behaviour (Huang, Benford, Hendrickx, Treloar, & Blake, 2017).

4.1.1 The role of the study in the Behaviour Change Wheel-guided process

Figure 3 has summarised the behaviour change intervention design process following the behaviour change wheel (BCW). The study presented in this chapter fulfils Step 4 by identifying what needs to change, and partly fulfils Step 5 – 6, by nominating a list of intervention functions and policy categories that are potentially effective to target the identified determinants. Chapter 5 will complete Step 5 – 6, by narrowing the list of candidate intervention functions and policy categories identified in this chapter down to a smaller set of intervention options appropriate for this research context based on the

APEASE criteria (affordability, practicality, effectiveness/cost-effectiveness, acceptability, side-effects/safety, equity) (Michie et al., 2014).

4.2 Method

4.2.1 Recruitment

The study was promoted via posters, news bulletins and staff mailing lists (see Appendix 2 for promotional materials) at the University of Nottingham, and 2 non-profit organisations (NPO), of which one was a creative technology education provider and the other was a culture event venue. Interested office workers were directed to an online screening questionnaire to sign up for the study (Appendix 3). Any office worker self-reporting spending at least 2 days of the week in sedentary (chair-bound most of the time) or semi-sedentary (intermittently chair-bound and moving around but without substantial walking or physical labour) jobs was eligible for participation; those who had no discretion over timing of micro-breaks were excluded for the study, because changing those peoples' patterns most likely required organisational or regulatory changes that were beyond the scope and possibility of this doctoral research.

4.2.2 Procedure and Materials

The researcher travelled to eligible participants' workplace to conduct a briefing interview that lasted 15 minutes, either during lunch hours or after office hour. After briefing and obtaining informed consent (Appendix 4) from participants, the researcher administered the pre-study survey protocol (Appendix 5). The pre-study survey included some general questions about the participants' job roles, work routines, break settings, and working habits, as well as the Occupational Sitting and Physical Activity Questionnaire (OSPAQ) (Chau, Van Der Ploeg, Dunn, Kurko, & Bauman, 2012). The OSPAQ is widely used and validated questionnaire measuring occupational sitting and physical activity and validated in several studies (Jancey, Tye, McGann, Blackford, & Lee, 2014; van Nassau et al., 2015).

Then the participant was given a diary pad, along with detailed verbal and written instructions of the diary protocol (Appendix 6), including any etiquette and privacy issues related to photographing third parties. Participants were requested to record the following 2 workdays as continuous series of sitting and break episodes, and note down the time whenever they left and returned to seat (Appendix 6 - Workday summary). Participants were informed that "a break is defined as any interruption in sitting in this particular study". For each break, participants would also need to take a photo (see example in Figure 13) of the physical context of this break and complete a "work break experience" form (Appendix 6 – Work Break Experience Form), which elicited in-situ responses about the decision and experience relating to the break; for instance, the form asked participants to complete sentences such as the following , "I wish I had taken this break earlier/later (delete where inappropriate), because…". To some extent, the in-situ diary could be considered an application of event-contingent experience sampling method (Csikszentmihalyi & Larson, 1987).

The diary protocol was designed to reduce recall bias while minimizing burdens on participants. First, participants could report as much or little as they want in situ (e.g. just note down the timestamp of leaving and returning to seat) and supply more details at the end of the day (e.g. complete the "work break experience" form). Second, participants were strongly encouraged to submit pictures of objects that were central to the experience and decision about their work breaks, if they were in a hurry. They could take photographs of anything just to help themselves recall and complete the diary without sharing them with the researcher. Such approach of combining photo-based experience sampling with end-of-day diary has been used in research before and found to significantly improve the quality of end-of-day recall (Yue, Litt, Cai, & Stern, 2014).

A reminder sign was placed in places where the participants would usually see during or just before breaks (e.g. at the exit of one's cubicle) to remind him/her to take photos and enter the break events into the diary.

When participants expected an unusual day (e.g. fieldwork, conferences or travels that were not a typical part of workday routines), they were asked to complete the diary on the next possible workday. The diary was collected once 2 full workdays were recorded.

Semi-structured interviews were conducted within a week following the collection of diaries. Prior to each interview, the researcher reviewed all diaries and marked specific events or behavioural patterns pertinent to theoretical constructs (Cane et al., 2012) for elaboration and clarification in interviews.

The researcher also transcribed diary entries onto a spreadsheet, which was then used to produce a visual representation of the sit-break pattern for each participant (Figure 9). In addition, 2 graphs with dummy data were created that illustrated 2 disparate workstyles, namely "Workstyle 1" that featured a break in every 2 to 3 hours, and "Workstyle 2" that featured a break in every 45 min to 60 min of sitting (Figure 10). Those dummy examples were meant to facilitate discussion on the pros and cons of different workstyles. Starting from Participant 8, a ranking of participants based on their daily time spent on prolonged sitting episodes was produced as an additional interview probe (Figure 11).

Each interview was audio-recorded with participant's consent. The interview questions covered 2 broad categories of topics: (i). Behavioural determinants guided by the TDF (see example questions in Table 6 and full interview questioning route in Appendix 7); (ii). Workday routines, work break experience, and desirable features of a potential technology designed to encourage breaks.

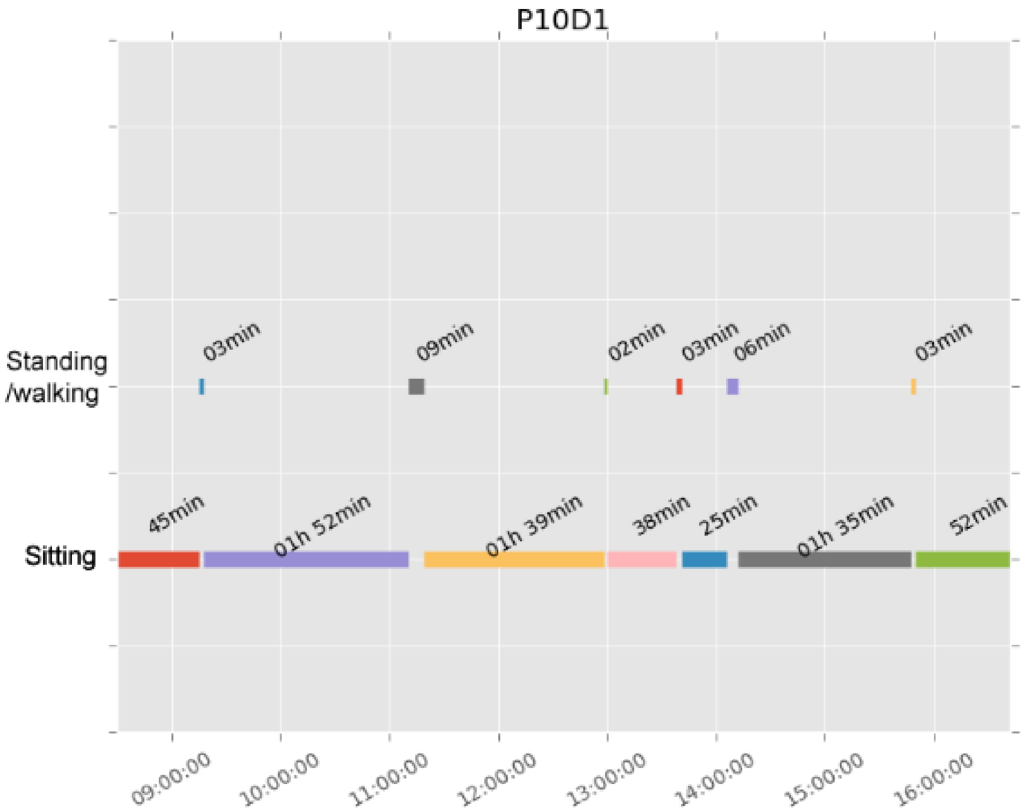

Figure 9 Example sit-break pattern graph produced based on participant's diary entries

Figure 10 Two graphs of sit-break patterns created from dummy data to facilitate discussion

Pid	Day	day start	day end	workday length	total sit	sitting%	mean	median (hh:mm)	shortest (hh:mm)	longest (hh:mm)	total sit events	events >1 hr	events > 2hrs	sitting > 1 hr	sittting > 2 hrs
7	2	07:50	15:15	07:25	06:24	86.29%	00:42:40	00:40	00:15	01:23	9	1	0	01:23	00:00
7	1	07:30	16:30	09:00	06:39	73.89%	00:36:16	00:38	00:10	01:15	11	2	0	02:17	00:00
2	2	09:30	17:30	08:00	06:31	81.46%	00:48:52	00:44	00:35	01:21	8	2	0	02:23	00:00
13	2	08:20	16:00	07:40	06:24	83.48%	00:48:00	00:49	00:10	01:23	8	2	0	02:45	00:00
14	1	09:00	16:57	07:57	06:58	87.63%	00:52:15	00:54	00:19	01:44	8	2	0	02:51	00:00
14	2	08:30	16:20	07:50	06:55	88.30%	00:46:07	00:39	00:14	01:46	9	2	0	02:51	00:00
11	2	09:05	17:40	08:35	06:51	79.81%	00:51:22	00:38	00:25	01:40	8	2	0	03:06	00:00
2	1	09:30	18:20	08:50	07:32	85.28%	00:56:30	01:00	00:25	01:10	8	3	0	03:27	00:00
12	1	08:00	16:15	08:15	07:38	92.53%	00:57:15	00:54	00:15	01:50	8	2	0	03:30	00:00
9	2	08:00	18:09	10:09	08:54	87.68%	00:59:20	00:57	00:25	01:55	9	2	0	03:38	00:00
1	2	08:00	17:03	09:03	07:11	79.37%	00:47:53	00:55	00:07	01:35	9	3	0	03:51	00:00
15	1	07:55	17:00	09:05	08:07	89.36%	01:00:52	00:55	00:40	01:30	8	3	0	04:02	00:00
11	1	08:36	17:30	08:54	07:37	85.58%	00:50:47	00:40	00:06	01:22	9	4	0	05:03	00:00
10	1	08:30	16:42	08:12	07:46	94.72%	01:06:34	00:52	00:25	01:52	7	3	0	05:06	00:00
13	1	08:20	16:00	07:40	07:13	94.13%	00:54:07	00:59	00:10	01:40	8	4	0	05:14	00:00
3	1	09:10	17:00	07:50	07:05	90.43%	01:10:50	01:07	00:20	01:50	6	4	0	05:50	00:00
10	2	07:47	16:12	08:25	07:56	94.26%	01:08:00	01:19	00:11	01:58	7	4	0	06:55	00:00
15	2	07:45	16:00	08:15	07:36	92.12%	01:05:09	00:50	00:30	02:00	7	3	1	05:03	02:00
4	1	10:00	17:00	07:00	06:41	95.48%	01:20:12	01:56	00:10	02:04	5	3	1	05:58	02:04
8	1	08:15	16:45	08:30	06:24	75.29%	00:54:51	00:57	00:05	02:05	7	3	1	04:22	02:05
9	1	08:50	16:55	08:05	07:24	91.55%	00:49:20	00:35	00:08	02:10	9	3	1	04:55	02:10
3	2	09:00	17:30	08:30	07:35	89.22%	01:15:50	01:22	00:15	02:20	6	4	1	06:55	02:20
1	1	07:30	17:15	09:45	07:21	75.38%	00:55:07	00:39	00:05	02:33	8	3	1	05:21	02:33
5	2	10:58	19:54	08:56	08:08	91.04%	01:01:00	00:39	00:07	03:03	8	2	1	05:01	03:03
6	2	07:42	16:34	08:52	08:16	93.23%	01:10:51	01:08	00:17	02:17	7	4	2	06:57	04:21
5	1	10:05	18:11	08:06	07:35	93.62%	01:05:00	00:23	00:07	03:22	7	3	2	06:35	05:22
8	2	08:25	17:00	08:35	07:47	90.68%	01:06:43	00:31	00:02	03:08	7	3	2	06:47	05:34
4	2	07:45	18:36	10:51	07:35	69.89%	01:53:45	02:13	00:10	02:59	4	3	2	07:25	05:40
12	2	08:15	17:45	09:30	08:55	93.86%	01:16:26	01:00	00:23	02:10	7	3	3	06:12	06:12
6	1	07:45	17:40	09:55	08:39	87.23%	01:14:09	01:17	00:12	02:18	7	4	3	07:37	06:20

Figure 11 Ranking of participants based on healthiness of workdays

Table 6 Interview topic guide based on COM-B and TDF

COM-B	TDF Domain	Eliciting Questions
Psychological Capability	Knowledge	What do you think would be the ideal work break pattern? How did you get to know about it? What do you think it is based on?
	Skills	How easy or difficult would you find it to follow workstyle 2?
	Memory, attention and decision process	If it were not for this study, would you always have an idea of how long you've been sitting for?
		Was that break a conscious decision? What were your thoughts when you decided that?
	Behavioural regulation	Do you set any rules for yourself regarding when you should stand up and move around?
		Do you have a system to help monitor whether you have taken regular breaks on workdays?
Reflective Motivation	Belief about consequences	(Show two work break patterns) Which of the two do you think is better? Why? How convinced are you? (prompts: in terms of health, productivity, social and mood consequences respectively)
	Belief about capabilities	Would you find it helpful to have a piece of technology that 1) monitors and displays your sitting time 2) triggers inactivity alerts 3) gives you feedback on your break pattern at the end of each day?
	Optimism	How confident do you feel about breaking up your sitting with regular micro-breaks?
	Goal	Do you want to change your current sitting patter in any way?
		Compared to the goal of completing your work, to what extent is having a healthier work pattern a priority for you? What about in the long-term?
	Intention	Is taking regular micro-breaks something you intend to do?
	Social/professional role and identity	Is sitting and working at desk for a prolonged period of time consistent with your professional standard? To what extent do you see yourself as someone conscious of the health impacts of your own lifestyle choices?
Automatic Motivation	Reinforcement	Would you say that generally you are in the habit of sitting for over 60 minutes/taking regular breaks? If not, what would be helpful in developing/breaking that routine/habit?
		Do you feel your break time experience is rewarding enough at the moment?

	Emotion	Does taking a break evoke an emotional response? Is the decision to take breaks influenced by any emotion?
Physical Opportunity	Environmental context and resources	What break facilities would you like to have access to?
		Are there any other factor that facilitates or hinders micro-breaks? (e.g. nature and structure of work that demands long period of concentration to get into the flow/for consistent outcome)
		How do you like the idea of having a smart cup in the office that prompts breaks?
Social Opportunity	Social influences	What's the culture of taking breaks in your workplace?
		How do your manager/supervisor perceive taking regular breaks?
		Would you feel part of a "crowd" or any social pressure if you follow workstyle 2?
		How do you find the ranking I showed you? Would you be motivated by that?

4.2.3 Data Analysis

To retain links between quotes and individual respondents, the Framework Approach to qualitative analysis (Srivastava & Thomson, 2009) was used – the author read through all interview transcripts and coded relevant quotes onto TDF domains and COM-B components. Coding was then reviewed by two health psychologists familiar with the BCW (one was the author's secondary supervisor, the other was Anna Roberts, a doctoral researcher in health psychology from the Centre for Behaviour Change, University College London) after which minor revisions were made. Afterwards, the author summarised sub-themes on perceived determinants emerging under each domain and counted their frequency. A domain was judged to be relevant, if it had common belief(s) shared by over 10 participants, or competing beliefs raised by over 10 participants.

4.3 Results

4.3.1 Recruitment and compliance

A total of 36 participants responded to posters and email advertisement and signed up for the study via the online screening questionnaire. Out of those, 2 were ineligible because they were PhD students rather than full-time employees; 3 were ineligible because they spent less than 80% of workday sitting and hence considered not sedentary enough for the study; 3 were excluded because they were on client-facing roles that made it inconvenient to take photographs; as the study advertisements attracts many university admin workers, 4 were put on the waiting list as they signed up and excluded at the end of recruitment so that the sample could represent more diverse job roles. 24 participants were contacted by the researcher to schedule a briefing session. Out of those, 3 did not respond to the researcher's communication or did not show up for the scheduled briefing; a total of 21 participant were consented. 1 participant withdrew on the first day of keeping the diary, because he found it "too disruptive to normal work". 20 participants completed the whole study protocol.

4.3.2 Sample characteristics

A total of 20 eligible participants were recruited (see characteristics of the sample in Table 7). They were employed on a variety of office-based roles including project management, communication, IT support, clinical research administration, filmmaking, teaching and research. It should be noted a majority (n=11) of the participants' work were related to the healthcare system or health sciences research.

Table 7 Baseline characteristics of feasibility study sample (n=20)

Characteristic	**Value**
Age in years, mean (SD), range	35.4 (11.4), 22 – 55
Gender, n (%) Male, n (%) Female, n (%)	 8 (40%) 12 (60%)
Highest education level completed, n (%) University preparatory degree, n (%) Undergraduate degree, n (%) Postgraduate degree, n (%)	 1 (5%) 7 (35%) 12 (60%)
Self-reported occupational time spent in sitting (hrs), mean (SD), range standing (hrs), mean (SD), range walking (hrs), mean (SD), range heavy labour (hrs), mean (SD), range Total office hours	 6.8 (0.7), 5.9 – 8.4 0.5 (0.4), 0 – 1.4 0.7 (0.4), 0.07 – 1.7 0.0 (0.1), 0 – 0.475 8.0 (1.0), 7 – 10
Height (cm), mean (SD), range	173.3 (12.5), 152 – 211
Weight (kg), mean (SD), range	73.6 (17.9), 50 – 120
BMI (kg/m^2), mean (SD), range Underweight (=<18.5), n (%) Normal (18.5 – 24.9), n (%) Overweight (25 – 29.9), n (%)	24.2 (3.7), 19.0 – 32.4 0 (0%) 14 (70%) 3 (15%)

Obese (>=30), n (%)	3 (15%)
Office layout and (number of officemates)	
Private (no office mate), n (%)	2 (10%)
Small shared office (with <=5 office mates), n (%)	10 (50%)
Open plan office (with >5 office mates), n (%)	8 (40%)
job role, n (%)	
Academics (including faculty members and research fellow/assistants)	6 (30%)
Freelance filmmaker, educator	1 (5%)
Clinical/nursing research administrator/assistant	7(35%)
Other types of knowledge workers (e.g. project management, communication, IT support)	6 (30%)

4.3.3 Diary summary

A total of 40 participant days (2 days/participant × 20 participants) of data were collected, with a mean duration of 506 (SD=50) minutes, or 6 hours 46 minutes. The dataset consisted of 319 sitting episodes and 291 break episodes. The sitting episodes had a mean duration of 58 (SD=39) minutes, whereas the break episodes had a mean duration of 9 (SD=7) minutes. The longest sitting episode was 3 hours 22 minutes. 105 sitting episodes were classified as "prolonged" events (i.e. lasting longer than 60 minutes), making up 32.9% of the total siting events and 59.1% of the total sitting time. A day-level (n=40 days) analysis revealed that a mean of 86.4% (range: 68.9% to 96.0%) of daily working time was spent on sitting.

An individual level analysis revealed that none of the 20 participants adhered to the recommendation of breaking up sitting with hourly breaks, as prolonged sitting episodes were present in all of the daily records and ranged from 1 to 4 episodes (median=3) per day. The longest sitting episode found in each individual's dairy ranged from 1 hour 04 minutes (P18) to 3 hours 22 minutes (P5), which suggested a common need for intervention that targets prolonged sitting is needed by all participants

4.3.4 Relevant TDF Domains and COM-B components identified

The qualitative analysis of interview data revealed facilitators and barriers to the target behaviour (i.e. break prolonged sitting with hourly micro-breaks) in 11 associated TDF domains and 5 relevant COM-B components, as summarised in Table 8. The rightmost column presents frequency with which each belief was mentioned among 20 interviewees; **bold** fonts indicate prevalent belief(s) that were shared by over 10

Table 8 Summary of sub-themes mapped onto COM-B and TDF with frequency counts

COM-B	TDF domains	Sub-themes about perceived facilitators and barriers	FQ. (n = 20)
psychological capability	1. Knowledge	unsure about the optimum break interval or scientific rationale behind it	**16**
	2. Memory, attention and decision processes	forget to take breaks: entrenched in work, lose track of time and don't notice bodily needs for breaks	**18**
		forget how many breaks have been taken and how much (prolonged) sitting have been accumulated on the day	**20**
		complex decision process that needs to take into account of many factors and that would benefit from a decision support system	**15**
	3. Behavioural regulation	need to break existing habit and apply new "if-then" rules	**13**
		need a system to ease self-monitoring of break behaviours, provide feedback on my behaviours and progress over time	**12**
Reflective Motivation	4. Beliefs about consequences	**health consequences:** a. believe micro-breaks have independent health benefits	**11**
		b. unconvinced of benefits of micro-breaks	9
		- believe exercise outside of work compensate for adverse effects of sitting at work	5
		productivity: a. overall speaking, workstyle 2 (hourly break) is more productive than 1	**13**
		b. overall speaking, workstyle 2 is less productive	7
		- workstyle 2 is particularly unproductive for some tasks	**14**
		- social interactions during breaks interrupt thinking	5
		Social consequences: a. negative: other people will notice and disapprove of or negatively perceive it if I take regular breaks	5
		b. minimal or positive: no one pays attention to or judges me if I take regular breaks; or there is even positive attitudes towards breaks	**15**

	5. Beliefs about capabilities	Automatic tracking and prompts/cues will give me confidence to start taking regular breaks	**12**
		Feedback will give me confidence to achieve my goal by knowing whether I'm improving or not.	**15**
		Despite some difficulty at the beginning, it will be easier to maintain once I get into the habit.	**11**
	6. Goals	Workstyle 2 is mentally represented as a desired end state but the goal priority and accessibility can vary across contexts	**11**
	7. Intentions	a. having taken an action towards the target behaviour change	7
		b. contemplating or preparing for the target behaviour change	10
		c. no intention to change even after participating in the study	3
Automatic Motivation	8. Reinforcement	a. existing habits that contribute to regular break behaviours	**12**
		b. existing habits that contribute to prolonged sitting	**12**
	9. Emotion	breaks evoke positive affect or remove negative affect	**12**
		breaks evoke or do not help with negative affect, or negative affect hinders micro-break behaviours	10
Physical Opportunity	10. Environmental context and resources	heavy workload and tight deadlines impel me to sit and work continuously longer than I would like to	**15**
		need prompts/cues; existing reminders have flaws in design	**20**
		the organisational culture and climate a. encourages micro-breaks and active work culture	10
		b. neither encourages or discourages breaks despite flexibility	7
		c. discourages regular breaks and I feel I am being watched	3
Social Opportunity	11. Social influences	**direct social interactions** that a. prompt breaks (e.g. social support, invite each other for breaks, short or walking meetings)	11
		b. inhibit breaks (e.g. bring drinks back to seat for each other, prolonged meetings without comfort breaks)	5
		social norm and social pressure: a. other people are good at taking regular micro-breaks and there is no pressure on sitting down to work	10
		b. other people sit quite a lot and prolonged sitting is perceived as hard-working	7

participants, whereas underlines indicate competing beliefs held by a total of over 10 participants.

4.3.5 Influential factors of occupational sitting and break behaviours

This subsection will highlight 6 important high-level themes, summarised from sub-themes in Table 8. For each quote, the respondent's gender, job and employer/work setting(s) are specified.

4.3.5.1 Theme 1 – Beliefs about consequences and knowledge

There was high variability across 20 participants in their *beliefs about consequences* of different work break styles. Only 11 participants strongly believed in the health benefits of regular micro-breaks, whereas the rest thought prolonged sitting would not affect themselves for various reasons, one of which was being young:

"I think at the moment, I'm 25 so I'm not as concerned about the health implications, I am aware of them." – P14, female, clinical research admin, university/healthcare

There was also the belief that engaging in sufficient physical activities outside of work (e.g. walking, cycling, gym) compensated for the adverse impacts of being sedentary in the workplace, which potentially increased risks for more sedentary time at work. The health impacts of prolonged sitting independent of exercise were unknown to most participants, even those working in healthcare organisations:

"I think my pacer has a target of 10, 000 steps. When I lived in Manchester, I always exceeded it. I would definitely say more sedentary in the work space (in Manchester), but I did far more steps overall because…just going there and coming back, I'm at 11,000 steps, so I don't feel the need to do anything when I'm there, whereas in Nottingham I feel so lazy because I can't walk to work or anything so I do try and do a little bit more." – P3, female, researcher, university/healthcare

"Nothing has been communicated to me (on health impacts of excessive and prolonged sitting) from the NHS (National Health Services), but I guess sitting down and not moving for any long period of time isn't going to be good for heart disease and stuff. But I feel that I counterbalance that by the fact that I cycle to work, probably 2 or 3 times a week." – P8, female, communication officer, NHS (university-based office)

Related to beliefs about health consequences, limited *knowledge* of the optimum break interval or scientific rationale behind it was another barrier to taking regular breaks. Although musculoskeletal and visual health benefits of taking breaks were mentioned, the cardiovascular health impacts of breaks were not well known. For instance, 16 participants expressed doubts over the credibility of commonly recommended break intervals:

"Only because my watch tells me every hour to get up...but until you send a non-Apple-paid doctor in front of me and tell me you absolutely should stand up every hour. Then I would do it…I mean I know from playing video games and from health and safety things that they say 'take a break of 15 minutes every hour' but I've never felt any particular effects from going any longer…" – P16, male, filmmaker, NPO

In terms of impacts on productivity, 13 participants believed regular micro-breaks had an overall beneficial effect on work compared with prolonged seated work, which was a potential motivator for taking breaks:

"I think mentally it probably is (better for work), because it actually gives your mind and body that time to step away." – P11, male, manager, NPO

"The trouble is if you get into that world of continually pushing through, I actually find I'm producing less because I go at it and then your brain goes, 'right, enough, I just can't think anymore, I've gone as far as I can go.' You can sit there and stare at the screen but you're not going to produce anything." – P18, male, IT support/project manager, university

However, 14 participants raised the concern that regular micro-breaks were particularly unproductive for certain tasks (e.g. programming, writing), where continuity was important:

"Because my job is quite creative, when I'm in the flow, it's really hard if you get interrupted to just switch back into that." – P8, male, communication officer, NHS (university-based office)

Participants' concerns that taking break would interrupt "train of thought" was partly due to the high cognitive demands and limited psychological capabilities (e.g. *memory, attention and decision processes)* during work time, which will be further delineated under Theme 3.

4.3.5.2 Theme 2 - Intention and goals

The variability in *beliefs* was mirrored by the variability in participants' *intentions* to adopt a more regular break pattern. 9 out of 20 participants had clearly made the decision and some efforts to improve their break patterns before participating in the study, *"I looked at this about two months ago, just apps for the MacBook for reminding you to take breaks."* – P2, male, project coordinator, NPO); 10 participants started contemplating or preparing for the target behaviour change after taking part in the study (e.g. *"I think it wasn't long enough to change my behaviour then. But now I'm perhaps more aware of making sure I get up and make a drink…But even though I know I would be healthier…it's like I need that motivation to actually do it."* – P12, female, clinical research admin, university/healthcare); 3 participants still had no intention to change by the end of the debriefing interview (e.g. *"I don't find that I have any problems from sitting at work, so I guess that's probably a healthy position to be in."* – P19, female, clinical research admin, university/healthcare). The variability suggested that social cognitive constructs in the *intentions* domain, such as behavioural intention (Ajzen, 1991) and stages of change (Prochaska & Velicer, 1997) could still be relevant to the target behaviour to a certain extent.

Participants' motivations to break up their sitting with micro-breaks fluctuated at different times, suggesting the relevance of the *goals* domain, and its distinction from the *intentions* domain. According to the TDF, an intention refers to a conscious decision or resolve to act in a certain way, which is relatively stable, whereas a goal is the mental representation of a desired end state, which can become more or less accessible to one's mind depending on the context (Cane et al., 2012). According to 11 participants, an hourly break pattern was a desirable end state (i.e. a goal), but priority and accessibility of this goal varied across contexts:

"I had several documents open, trying to match things up, I didn't want to interrupt my train of thought, but I know it's good. Just there are so many other things going on, it is a low priority (to take breaks)." – P7, female, clinical research admin, university/healthcare).

"In my mode as I am now trying to be good, saying it is a good idea to break every 50 or 60 minutes, I am going to say if the display is there and it makes you break earlier, then that is good. But if I am really into whatever I am doing, I would throw it out of the window or something." – P9, male, academic, university

Although most participants agreed on the importance of taking regular breaks and maintaining long-term health during the interviews, such distal goals usually had to give way to more proximal work-related goals in the office environment:

"…because that's so long term, whereas you can see the short-term effects and take that on board more." - P13, female, clinical research admin, university/healthcare

4.3.5.3 Theme 3 - Lack of psychological capability for managing interruptions

Memory, attention and decision processes was another important domain underlying break behaviours.

In relation to the previous theme on *beliefs about consequences* of taking breaks, many participants reported taking physical breaks while still thinking about work as a way to mitigate productivity loss resulting from breaks. Breaks as such were not particularly cognitively demanding:

"Even though you're walking to go to the loo, you might still be thinking on the task that you are doing or subconsciously so. You're not deep in it still, just on a little light level. Go to the loo, come back, you're still roughly in that same thing, you haven't got that 'getting-back-up-to-speed' ramp to climb…" – P18, male, IT support/project manager, university

However, extra cognitive resources were required when participants needed to engage in conversations with others:

"I mean getting up to go to the toilet doesn't have that much of an impact, but it's the distractions that you bump into on the way of that journey that causes the problem…the minute you take your headphones off it's like a window, it's like an advertisement to say 'I'm available to be spoken to'." – P16, male, filmmaker, NPO

"Chatting with a colleague sometimes can be rewarding but sometimes distracting, because when you are focusing on one thing, and because I'm foreigner, chatting is like switching my mind." – P5, male, researcher, university

The diary visualisations (Figure 12) showed that participants in this study who reported being frequently approached and interrupted by co-workers at work (e.g. P5, P8) had more prolonged sitting episodes than those without external interruptions (e.g. P7, P17).

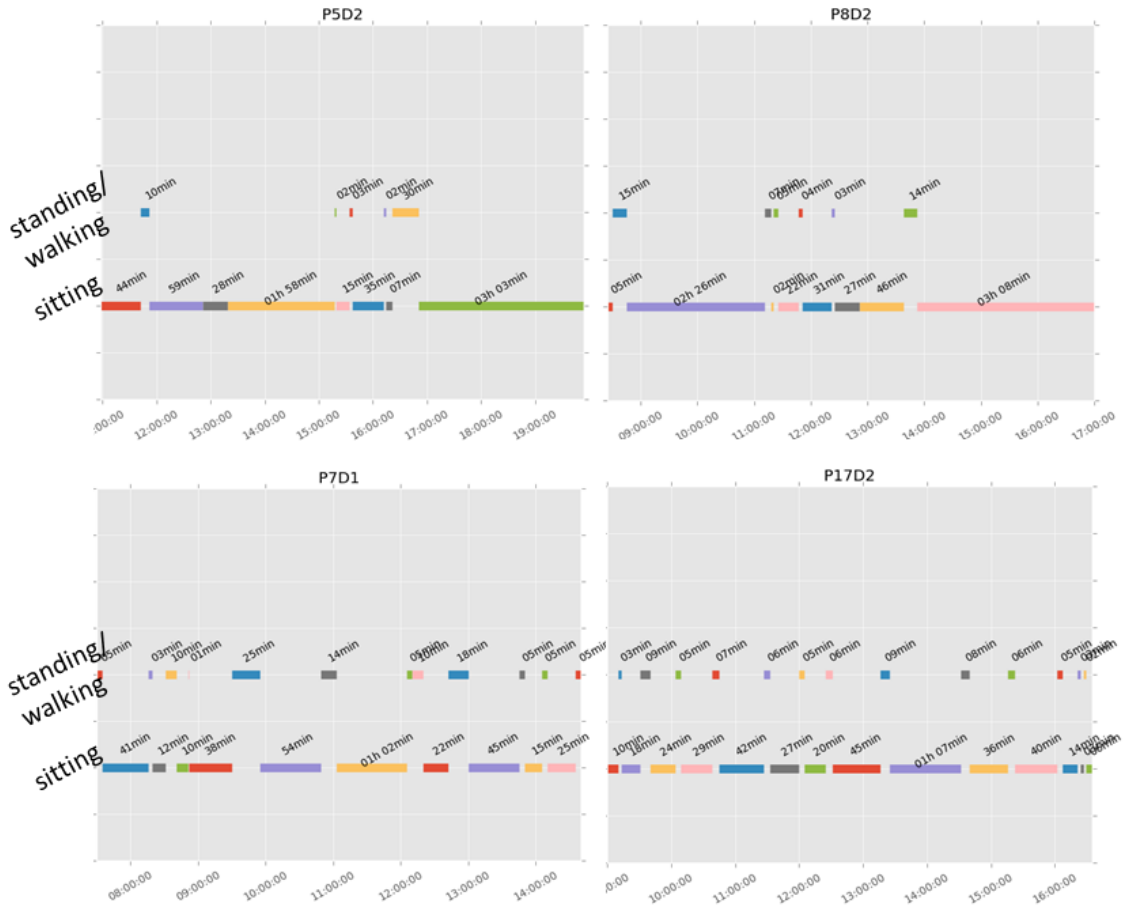

Figure 12 Work break patterns of participants who were frequently interrupted (P5, P8) versus who mostly worked on one's own without interruptions (P7, P17)

The interview quotes suggested 2 potential reasons for this phenomenon (i.) those with interruptions needed more time to get back to the flow and refocus on work (ii.) they deliberately delayed breaks to minimize the chance of being caught by others during breaks:

"so sometimes I'll try and block time in my diary, but I'll just get interrupted or people asking me questions…If I'm interrupted, it takes me a lot longer to concentrate and focus and go back in again to get the same flow where was before. So that's quite hard. Sometimes I can work for hours…" – P8, female, communication officer, NHS

"To get to it (the toilet), I have to walk all the way along there, out the door, into that little kitchen area… so just going from here to the toilet can be a mind field of just running into people, having conversations and all that sort of stuff. So you'd go back and think why am I going to the toilet so much? …" – P16, male, filmmaker, NPO

"…It might just be the colleague goes, 'hi, how are you?', 'I'm fine thanks' and then we move on; or it could be, 'Oh, I'm glad I've caught you…' and then your train of thought has changed. I've popped that sort of creativity bubble. I've changed tack. I'm now thinking about something else. I've got distracted. So, that's probably why I put things off…" – P18, male, IT support/project manager, university

According to interviews, the impact of interruptions seemed to be similar for participants with private and shared offices. It was the interdependence between individuals at work rather than the physical layout of the office environment that mattered.

4.3.5.4 Theme 4 - Lack of psychological capabilities for regulating break patterns

The decision on when to take a break was also influenced by the memory and attention capacity available at that moment. 18 participants reported the experience of being "engrossed" in work, losing track of time and forgetting to take breaks:

"I lose track of time very easily, especially if I'm coding. I know afterwards when I look at the watch and I see that it's been 3 hours and I haven't moved." – P1, female, academic, university

"I don't realise that two and a half hours have gone by and I thought it would say 10.30 and its actually midday." – P6, male, clinical research IT support, university/healthcare

Keeping a regular break pattern was described as a prospective memory task that would compete for cognitive resources with work-related tasks:

"But I think if you would do this (style 2) consciously, it would interrupt your work sometimes, because...you would have to remember to get up." – P7, female, clinical research admin, university/healthcare

As for attention, participants reported that concentration on work led to failure to notice physiological cues for breaks (e.g. thirst, tiredness, need to go to toilet). This will be further delineated under the next theme on habitual and impulsive responses towards cues for breaks. But the following quote illustrates how a lack of attentional resources contributed to this phenomenon:

"If we have got 10 units of attention and 10 units focused on the screen on what we are writing, then we are not going to notice that your foot hurts." – P9, male, academic, university

"It's hard because you focus on one thing, then you forget everything else. For now, I can say that I'm aware of and concerned about my kidney and my back. But when I'm working, the thought is gone." – P5, male, researcher, university

Retrospective memory of breaks also affected behaviours in the long term. The difficulty with recalling daily break patterns was identified as a key barrier to monitoring and improving break patterns over time:

"At the end of the day if you asked me how many times I took a break, I would not know." – P7, female, clinical research admin, university/healthcare

The visual feedback shown in Figure 12 was found potentially useful for supporting the development of *behavioural regulation* skills such as goal setting and self-monitoring:

"I think if the technology would be there, it would make me work much better to that pattern...especially if it would be something where I would look back on what I've done and then just review myself in actually you're improving or not improving on what I want to do." – P7, female, clinical research admin, university/healthcare

This had implications for the *beliefs about capabilities* domain, as participants thought a record of breaks like the paper diary used in the study offered the reassurance that they were more capable of keeping a regular break pattern than they had thought:

"*It (the diary) made me realise I'd taken a break that perhaps wouldn't normally even register in my head that I'd taken a break.*" – P6, male, clinical research IT support, university/healthcare

"Sometimes my breaks are so short that I didn't consider them as breaks. But I had to write them down. Then I thought, ah, that's a nice break. Even if it was 5 minutes, that's something." – P1, female, academic, university

Finally, a conscious decision on when to take a break might need to take into account of many factors, such as progress in the current task, physical and mental fatigue, impacts on productivity, next appointment arrangement etc:

"*if I had a task I needed to complete for a meeting for 11:00 a.m., I'd look at that break reminder and go, 'right, am I going to get this stuff done for 11:00 a.m., if I have a cup of tea now?' I'd then either think, 'yes I am, I'll have a cup of tea because I know that the number of minutes after the break will be* *of a higher quality in terms of production and freshness than just pushing through', or I'd look and go, 'you know what – It's going to be pretty damn close for me to finish, what I'll do is I'll keep going and have a cup of tea as a reward when I've done it.' It's a judgement call on an individual basis*." – P18, male, IT support/project management, university

In addition to the timing of breaks, remembering to do things to care for personal health was also a process that would benefit from some sort of decision support (e.g. suggestion for appropriate break activities):

"Yeah. So that day I hadn't had any drink for that 45 minutes…I was thirsty, yeah, dehydrated. So I started to feel not well. I was getting a headache…If I remembered, I would have filled it up straight away before I started work. But I just forgot, and then I got side-tracked by checking emails, talking to people, then I realised I was feeling bad." – P10, male researcher, university/healthcare

Given the complexity of the decision process and scarcity of cognitive resources at work, many break-related decisions and behaviours were under the influence of the automatic system, as described in participants' diaries and interviews, which led to the emergence of the next theme.

4.3.5.5 Theme 5 - Habits, impulses and emotions related to breaks

Habits that facilitated and hindered regular break behaviours were both reported, suggesting the relevance of the *reinforcement* domain. 5 participants (P1, P7, P10, P13, P16) reported the habit of sipping water constantly during seated work, so they were prompted to stand up every hour or every other hour, by the need to go to the toilet and refill vessels:

"Because I'm drinking so much, I think it helps ultimately. Being in the habit of nearly always drinking quite a bit, I'm going to have to get up, aren't I?" – P13, female, clinical research admin, university/healthcare

The only smoker (P17) in this study had the least accumulative prolonged sitting time, as he felt a strong impulse to take a cigarette break every hour. While smoking is an unhealthy behaviour that should be certainly discouraged, the example illustrated physiological needs could act as an efficient (i.e. require little cognitive resources) and powerful (i.e. not easily controlled by intentions) mechanism that drove break behaviours and regulated overall break patterns.

"I mean, that's the thing, isn't it? My smoking is the thing that makes me take a break, but I can see how if someone doesn't have that kind of mechanism, and the only break they do have is like toilet, or drinking, stuff like that. They are physiological, but not necessarily as strong." – P17, male, admin, university

The automatic motivation could interplay with the reflective system and impact on higher-level cognitive processes such as goal pursuits (Bargh & Ferguson, 2000) and self-regulation (Aarts & Custers, 2012). Participants reported the uncontrollable impulse to delay breaks despite physiological needs for water and toilet breaks, if they were striving for work-related goals, especially in the face of heavy workload and tight deadlines. Moreover, discrepancy was observed between what participants believed were good for them on reflection and what they wanted in the moment:

"I'm a bit of an obsessive person. So once I start something, I wanna finish it, and I wanna see it through the end... I have no water, I have to go, but I want to finish this… Yeah, it's difference between what I wanted and what I needed." – P1, female, academic, university

Many participants (P1, P13, P14, P16) had also developed certain habitual patterns. For instance, some regarded natural "break points" of work tasks as contextual cues for breaks and saw the experience of breaks as a reward for completing a good amount of work:

"Yeah. I would make myself write a paragraph, or make myself write a page or something like that, before I would let myself then have a cup of coffee. Because anything is more attractive than writing at that time. It was kind of like bribing myself to write it, then have a drink afterwards. So I think it was just bad habit." – P12, female, clinical research admin, university/healthcare

However, the risk with this contingency was that a work task might take much longer to complete than expected, in which case, the break could be massively delayed. This suggested the relevance of the domain *behavioural regulation,* as office workers needed to develop new "if-then" rules to override existing contingencies and engage in more detailed action planning to cope with various situations:

"Sometimes you plan it and then you don't plan it correctly and it takes a lot longer. It would've been good for a trigger at one hour to say this is when you should have stopped, you haven't, but you should have a break anyway." – P14, female, clinical research admin, university/healthcare

The domain *environmental context and resources* could also be relevant, as prompts and cues would help break old habits and facilitate formation of new habits. Participants talked about limitations of technological tools they had used for reminding themselves to take breaks:

"Having something to remind you to get up in regular intervals would be quite useful...the watch isn't very clever, I mean today I got up to make myself another drink and then sat back down and then it pinged to say oh it's time to get up. And I'd just literally got up - so it doesn't feel like it follows me, like it must be more of a time thing…" – P16, male, filmmaker, NPO

Finally, modifying ingrained work patterns could also involve *emotions*. For instance, P6 (male, clinical research IT support, university/healthcare) reported that his prolonged sitting habit stemmed from 20-year working history at a small private company in the finance industry, where *"everything was urgent. If things broke down, they needed them repairing and you had to deal with it immediately"*, and this sense of urgency continued to influence his current work practice: *"I think the biggest thing for me is to not feel so guilty if I'm running behind schedule"*.

In contrast, P7 (female, clinical research admin, university/healthcare) who engaged in less prolonged sitting had much more positive affects toward taking breaks: *"because I know it is better for you, so I enjoy taking the breaks and don't feel guilty about it."*

This suggested emotions could influence break behaviours in both directions and could act as a potential lever for change.

4.3.5.6 Theme 6 - Organisational culture and interpersonal influences

While all participants in this study had freedom to take micro-breaks, the types of organisational culture and levels of management control over breaks varied from encouraging active and interactive work practices, through no explicit expectation or surveillance, to discouraging breaks. The following quotes illustrated these 3 types respectively:

"The team I'm in, they're not negative in terms of what I would call presenteeism. In some ways I think we are encouraged even, to be active and engaged…You judge a person on what they do rather than how they look or where they are." – P18, male, IT support/project management, university

"I feel alright to take a break whenever, because they don't know what I'm doing as well." – P4, female, researcher, university/healthcare

"the manager will come and say 'Where's so and so? They're not in a meeting according to my diary. Why aren't they sitting at their desks?'" – P20, female, tech support, university

The study identified interpersonal influences on break-related attitudes and behaviours via social comparison and subjective norms. When participants were presented with the ranking based on healthiness of their own sitting patterns against those of others, they started comparing their own data, both upward with those at the top and downward with those at the bottom:

"(the ranking)…makes you see how close to the top of this league you can get by having the appropriate number of breaks, never sitting for too long" – P9, male, academic, university

"(I'm) fairly competitive. If I'm doing something, I like doing well. It's something that would drive me to do more if I knew I was competing against my friend or my colleagues, you know, or just random people. I think that will be interesting." – P10, male, researcher, university/healthcare

"I feel pretty chuffed. I'm, yeah, I'm better than a lot of people." – P14, female, clinical research admin, university/healthcare

However, not all participants were influenced by the comparison with others on work break behaviours:

"Not really. because I know I'm comparing myself with other people who are not necessarily healthy, either...I suppose I've not really chosen to be near the top and near the bottom…the meetings force me to be active." – P12, female, clinical research admin, university/healthcare

Moreover, presentation of data about individual sitting time could be interpreted in a way that sabotaged rather than serving the original health-oriented initiatives:

"When I was writing this, it did make me think that this is a bit like the old-fashioned working time type studies that people used to do – 'oh, wait a minute, how long does it take you to do this item on a production line? How long does it take you to screw this on?' So there could be an element of – can't remember the word for it – sort of analysing your working day to the point at which the expectation might be that…the longest is the one we're aiming for to be like… It could be to show how much harder they

are working, how much more are they risking their health for the team. You are not doing your bit." – P20, female, tech support, university

In addition to social comparison and normative social influences, social interactions could change break patterns and activities directly. For example, some offices had the culture of inviting each other to make drinks together (P4, P5, P7, P12-15), whereas others had the tradition of people taking turns to bring drinks for the remainder so that most people could remain seated and working for longer (e.g. P8, P11).

"If she says I'm gonna get a cup of tea, I'll go, 'oh I'll come with you', even if it's just like to stretch my legs or something." – P15, female, researcher, university/healthcare

"No. Someone will go and collect coffees for people and bring the back to the office. So everyone stays seated bar the one person who goes to collect. We wouldn't all go to the cafe and have a break." – P11, male, manager, NPO

The interview also suggested emotional and practical supports among colleagues could also facilitate breaks by helping reduce negative *emotions* (e.g. guilt) associated with taking breaks:

"because we are in a caring environment and people do care about their colleague's health...so I think if you felt that somebody else had been sitting there for longer than is healthy then I think you could say something to them." – P19, female, clinical research admin, university/healthcare

4.4 Discussion

4.4.1 Key barriers and intervention options

The purpose of this study was to apply the COM-B/TDF framework to identify what need to be changed in order for office workers to take regular (i.e. at least hourly) breaks at work. This section will discuss the themes identified both under and across the TDF domains; in addition, it extends one step further to the red and grey rings of the BCW to nominate intervention functions and policy categories. While not all intervention functions and policy categories identified based on results in this chapter are implementable in the doctoral research due to technical, financial and organisational constraints, they can nevertheless be considered by other researchers working in this field.

First, the findings of this study are consistent with other qualitative studies (Gardner et al., 2017; MacDonald, Fitzsimons, & Niven, 2018; Niven & Hu, 2018) and thematic synthesis (Hadgraft et al., 2018) in suggesting the relevance of *beliefs about consequences, intention* and *knowledge* to office workers' sitting behaviours. Specifically, office workers want to see health benefits of reducing sitting that outweigh and justify the perceived productivity loss over breaks. At the time of data collection for this study (early 2016), the independent health risks of sedentary behaviour were not yet widely communicated to the public. That was why 9 participants were surprised to find out at the end of the interview that physical activity and sedentary behaviour could have independent impacts on health. Ironically, over half of these 9 participants worked in healthcare-related fields with roles such as researcher, health communication manager and clinical trial manager. In addition, the study suggests the relevance of the TDF domain of *goals*. This has implications for intervention design, as setting up the goal to reduce occupational sitting may not suffice to enable behaviour change; the cognitive accessibility of the health goal also needs to be heightened in an office environment.

Applying the BCW, the intervention functions of education, persuasion, modelling, incentivisation and coercion, and the policy categories of communication/marketing, guidelines and service provision can be used to target the above barriers. The past 5 years have seen a spurt in public health messages on sedentary behaviour change as a separate behaviour from physical activity. A recent study (Gardner et al., 2017) examined how the public responded to an expert statement (Buckley et al., 2015) on sitting reduction in office-based workplaces. It was found that the public was suspicious of motives behind the guidance, perceiving public health as a conspiracy of scientists, industry, employers, politicians and the media, to serve hidden financial interests. This was echoed by quotes in the current study showing participants' concerns that collection and presentation of data about employees' sit-break patterns might strengthen employer's control over employees and promote competitions to sit and work more rather than less. Hence, caution should be made when incorporating social influences in interventions. This includes not only technical measures to ensure that data is used in a trusted and privacy-preserving way, but also carefully designed persuasive and educational materials to communicate the right message to the public without causing misunderstandings or adverse impacts on behaviours.

Second, this is one of the few studies that have comprehensively explored how different aspects of psychological capability such as *memory, attention and decision processes* influence office work break behaviours. One previous study has conceptualised sedentary behaviour problem as a prospective memory task (Grundgeiger et al., 2017), this study adds to the literature that break behaviour is influenced by both prospective memory (e.g. remember to take break on time) and retrospective memory (e.g. recall sitting time and break pattern at the end of the day) and suggests that supporting the latter can enhance *beliefs about capabilities* to improve break patterns in the long term.

Applying the BCW, intervention functions such as training, environmental restructuring and enablement, and the policy category of service provision may be used to target those determinants, by providing prompts and cues for breaks, offering feedback on sitting behaviours and supporting self-monitoring of behaviours over time. In addition, feedback can be accompanied with persuasion about capability and focus on past success to enhance self-efficacy (i.e. beliefs about capabilities). In contrast to other researchers' recommendation that sedentary behaviour interventions promote "mental breaks" (MacDonald et al., 2018), the current study suggests the possibility of mental interruptions actually demotivated people from taking physical breaks. A counterintuitive phenomenon observed in this study was that frequent interruptions seemed to be associated with more prolonged sitting episodes in this study. Despite the small sample size and the anecdotal nature of this finding, it suggests we should provide office workers with, at least, the option to take simple physical breaks while continuing rumination about work. Hence, sedentary behaviour interventions may incorporate tools and strategies for interruption management; the design of interventions should also be informed by a more thorough understanding of cognitive activities and mental workload during office work.

Third, the study reveals that social and physical opportunities have profound impacts on micro-break behaviours. Individual break behaviours are influenced by how co-workers take breaks and perceive breaks, both directly via social interactions, and indirectly via shaping beliefs, attitudes and affects toward breaks. Individual break behaviours are also influenced by the nature of work, workload, access to prompts and cues for breaks, as well as the broader organisational climate.

According to the BCW, the intervention functions of environmental restructuring, modelling, enablement and restriction, and the policy categories of environmental/social planning, guidelines, legislation, service provision and fiscal measures may be used to establish an organisational culture and office practice supportive of regular break behaviours. While organisational-level interventions and environmental changes are more commonly used and likely to be effective for addressing those factors (Coffeng et al., 2014; Neuhaus, Healy, Fjeldsoe, et al., 2014), the current study revealed the potential for lower-cost individual-level digital interventions to gain leverage from social interactions and interpersonal influences. For instance, the technology may enable office workers to identify and invite co-workers who are in need for a break to take breaks together, which may foster a pro-break culture over time. In other words, by acting on interpersonal factors, an intervention may gradually influence the workplace culture with a bottom-up approach. However, that will need to be balanced with the aforementioned individual preference on social interactions during breaks. Caution should be made in the presentation of social comparative information, as previous studies suggested competitions could demotivate lowly competitive individuals (Song, Kim, Tenzek, & Lee, 2010) and those at the bottom of the ranking; additionally, this study showed misinterpretation of employee occupational sitting information could sabotage rather than serving the original health-promoting goal.

Finally, it was evident from the study that automatic motivation was very influential on sitting behaviour in the workplace. While several studies have examined the influence of habits on sitting behaviours (Biddle, 2011; Conroy & Maher, 2013; Smith et al., 2018), this is the first study with qualitative quotes evidencing the interplay between psychological resources (memory, attention, and decision processes), automatic motivation (habits, emotion), reflective motivation (goal accessibility), physical opportunity (prompts/cues) and social opportunity (interruptions) in shaping sedentary and breaks behaviours in in office-based workplaces. Interview quotes indicate that heavy workloads and interruptions drain office workers' cognitive resources and make breaks more likely to be under the influence automatic motivation (e.g. impulse, habit, emotion). As discussed in Chapter 2, the formation of a new habit requires repeated responses towards an environmental cue, which will need to be directed and energised by an accessible goal.

Applying the BCW, intervention functions such as training and environmental restructuring and coercion and all 7 policy categories may be used to target habits. This approach has been implemented in previous studies in the form of prompt-based goal setting and habit formation techniques, and proved effective in reducing sitting in both office workers and elderly (McGuckin et al., 2017; White et al., 2017). Additionally, as per the BCW, enablement, modelling, incentivisation and coercion may be used to foster positive affects toward regular break behaviours and alleviate negative feelings associated with breaks. Action planning, commitment contract, self-monitoring and rewards have been shown useful to incentivise break behaviours by shortening the psychological distance of long-term goals (Edwardson et al., 2018; McGuckin et al., 2017).

4.4.2 Strengths and limitations

To the knowledge of the author, the study presented in this chapter was the first published systematic diagnosis of office workers' prolonged sitting and break behaviours guided by the COM-B/TDF. The study has the strength of using a validated theoretical framework to guide the construction of interview questions and analysis of data. Compared with other studies guided by the COM-B/TDF, this study additionally highlights how some factors in different TDF domains interplay with each other to influence behaviours in synergy.

The study has the second merit of using paper diaries to collect some initial information about the context of participants' work breaks, and to facilitate fruitful interview discussions. The visualisation produced based on the paper diary data was a low-cost yet powerful tool for eliciting user comments on the potential design of visual feedback prior to investment in technical development. Although used as a data probe rather than a valid source of behavioural data, the diary was useful in revealing the prevalence of sitting and prolonged sitting in office-based workplaces. The percentages of siting (87% of daily working hours) and prolonged sitting (59% of daily sitting time) recorded in the 2-day diary were even higher than those recorded in previous studies (60%-82% of working hours spent in sitting; 25%-50% of sitting spent on prolonged sitting) (Clemes et al., 2016; Fountaine et al., 2014; Parry & Straker, 2013; Ryan et al., 2011; C. Waters et al., 2016).

The study has several limitations that need to be addressed with further studies. First, although the COM-B/TDF approach does lend itself to a comprehensive coverage of factors to support generation of new research questions and hypotheses, the extent to which those factors, processes and intervention components interact with each other and impact on the behaviour will need to be tested with further experimental studies.

Second, the behavioural diagnosis left the author with the whole range of 9 intervention functions that could be potentially effective, which may or may not be appropriate for individual workplaces. Hence, other intervention designers may consider the recommended intervention functions and policy categories as potentially effective options informed by theories, but narrow the list down to intervention components most appropriate and feasible for their local contexts using the APEASE (affordability, practicability, cost-effectiveness, acceptability, side-effects/safety and equity) criteria (Michie et al., 2014). In this doctoral research, this step will be reported in the Chapter 5.

4.5 Conclusion

This chapter presented a systematic diagnosis of determinants of office workers' regular break behaviours. By using the COM-B model in conjunction with the TDF, the study informs intervention designs with a comprehensive theoretical understanding of the target behaviour. Barriers to regular break behaviours have been identified in 11 TDF domains and 5 COM-B components. This means a multi-component intervention that incorporates many of the recommended intervention functions more likely to produce the desired behaviour change outcome than a single-facet intervention. However, most of the time, intervention designers and researchers need to prioritize certain intervention components while giving up on others in intervention development, by taking into account of other requirements, which will be reported in the next chapter.

Chapter Five

Design and Development of the WorkMyWay intervention and technological delivery system

5.1 Introduction

This chapter describes the design and development of the *WorkMyWay* intervention, as well as of the technical implementation of the *WorkMyWay* Lite and Full systems, deployed later in an 8-week feasibility study (Chapter 6) to assess the baseline sedentary behaviour (SB) and to deliver the *WorkMyWay* intervention respectively.

The chapter is divided into 3 sections: (i.) design of the intervention content guided by the Behaviour Change Wheel (ii.) design of the intervention delivery system drawing on human-centred methods for designing interactive systems (iii.) the technical design, specification and implementation.

Although presented as 3 separate sections in a linear structure here, the 3 lines of activities were all iterative, and interwoven with each other in the actual process. Chapter 7 - Section 7.6.1 will reflect on connections between these different pieces of formative research and design activities.

5.2 Behaviour Change Wheel-guided intervention design

Chapter 1 has highlighted the importance of systematic use of theories and evidence in intervention development. Yet the scoping review in Chapter 3 demonstrates a paucity of design and development research in this field that has followed systematic approaches. To address the gap, the content development of *WorkMyWay* in this PhD project has been guided by the Behaviour Change Wheel (BCW) (Michie et al., 2014) to ensure that the resultant intervention has a solid and coherent theoretical underpinning. The BCW-guided intervention design process consists of 3 stages and 8 steps (Figure 3). The following sections report outcomes from each step.

5.2.1 Stage I. Understanding the behaviour

Chapter 2 has served Step 1 – 3 in the BCW-guided intervention process through a literature review and led to specification of the target behaviour as: *"office workers (ie. who) take ambulatory breaks to interrupt stationary behaviours (ie. what) at least hourly during work hours (ie. how often and when)".* The behavioural diagnosis reported in Chapter 4 fulfilled Step 4 by identifying determinants of the target behaviour in 11 associated TDF domains and 5 relevant COM-B components (e.g. psychological capability, reflective and automatic motivation, social and physical opportunity).

5.2.2 Stage II. Identifying intervention options

Step 5 and 6 are concerned with selecting the broad categories of means by which an intervention can change behaviours (i.e. intervention functions) and the type of decisions made by authorities that help support and enact the interventions (i.e. policy categories) respectively (Michie et al., 2014).

5.2.2.1 Identify intervention functions

Using the BCW guide table that linked the COM-B, TDF domains to intervention functions (Michie, Atkins, and West 2014, p.113), the behavioural diagnosis led to the suggestion of a whole range of 9 intervention functions that could be potentially effective. Judgement were made on which of these intervention functions were appropriate for the social context by applying the APEASE (affordability, practicability, (cost-)effectiveness, acceptability, side-effects/safety and equity) criteria.

The intervention function of "coercion" and "restriction" were excluded at this stage. Coercion conflicted with the user requirement for agency, autonomy and control over work break rhythms (to be reported in Section 5.3) and was therefore deemed unacceptable for the workplace context. It was also impractical and unacceptable to restrict office workers' access to seated workstations or prevent them from going to long meetings.

5.2.2.2 Identify policy categories

As for policy categories, at the beginning, the author made attempts to approach stakeholders and gatekeepers (e.g. HR mangers and staff wellbeing leads) within several organisations (e.g. educational institutes, local commissioning groups within the NHS) to solicit management endorsement for developing and deploying the intervention within the organisation and explore the potential for a multi-level intervention that would encompass organisational policy change. However, this was considered impractical, given limited time and resources in the doctoral research. Hence, the author opted for a "bottom-up" approach, by engaging end users (i.e. office workers) in designing and testing the intervention, which was framed as a potential consumer product that individuals could adopt for their own health. The author envisioned that the initial evidence on the service/product's benefits to staff health and wellbeing would encourage authorities and organisational gatekeepers to endorse and provide the service to a wider range of employees in the future. Hence, the policy category of "service provision" was selected from 7 policy categories (the other categories were communication/marketing, guidelines, fiscal measures, regulation, legislation, and environmental/social planning, according to the BCW).

5.2.3 Stage III. Identify content and implementation options

Step 7 is concerned with identifying intervention content in terms of selecting BCTs that best serve interventions functions. BCTs are "observable, replicable and irreducible components of an intervention designed to change behaviour (Cane et al., 2015) and are considered as the "active ingredients" within the intervention" (Michie et al., 2014). Step 8 is concerned with selecting the mode of delivery appropriate to implement the intervention. Mode of delivery is considered an important aspect of interventions and should be differentiated from the content of intervention (Carey et al., 2017; Michie et al., 2014).

5.2.3.1 Select behaviour change techniques (BCTs)

The BCW guide provides several ways of selecting BCTs. For instance, one can either start with considering the most frequently used BCTs under each intervention function or proceed directly from the TDF-based behavioural diagnosis to selecting BCTs. The author adopted a combination of the 2 approaches. The author first created a matrix (Table 9) to detail the internal links, between the COM-B components, TDF domains identified in the previous steps and the corresponding candidate intervention functions, as per the BCW guide, (Michie et al. 2014, p.151 - p.158) which was then used to identify potentially effective BCTs for each numbered cell. This resulted in a range of BCTs selected for Cell 1 - 32, as listed in Table 11, together with illustrative intervention components. BCTs initially nominated for Cell a - f were judged to be inappropriate based on the APEASE criteria (Table 10).

Table 9 Candidate intervention functions to target the COM-B and TDF domains

COM-B	TDF domains	Education	Persuasion	Training	Environmental Restructuring	Incentivi-sation	Enableme	Modelling
	Knowledge	1						
	Memory, attention and decision processes			d	11		19	
Psy cap	Behavioural regulation	a		e			20	26
	Beliefs about capabilities	2	5				21	27
	Beliefs about consequences	3	6					28
	Intentions	4	7			15		29
Ref mot	Goals	b	c		*12	16	22	30
	Reinforcement			9	13	17		
Aut mot	Emotion		8			18	23	31
Phy opp	Environmental context and resources			10	14		24	
Soc opp	Social influences				f		25	32

*Cell 12: according to the BCW, environmental restructuring was not commonly used to target the TDF domain of goal; however, the literature suggested environmental cues could be used to heighten accessibility of goals.

Table 10 Excluded BCTs because of not passing the APEASE criteria

Cell#	determinants	Intervention Function	BCTs	Reasons for not inclusion (APEASE Criteria)
a, d, e	memory, self-monitoring skills	Education, training	self-monitoring of behaviours	Impractical and unlikely to be effective to enhance memory and self-monitoring with training or education, as most cognitive resources are allocated to work-related tasks during office hours, leaving very little for remembering to take breaks and self-monitoring of break behaviours;
b, c	goals	Education, persuasion	information about consequences	Unlikely to be effective, as the key here is to heighten the accessibility of health-related goals in the situation with minimal information
f	social influences	Environmental restructuring	Restructuring the social/physical environment	Impractical to isolate office workers from sedentary co-workers

Table 11 Intervention mapping table

Cell#	Intervention Function	Constructs/Mechanisms of action targeted (Chap.4)	BCTs (Chap. 5)	Intervention components and mode of delivery (Chap. 5)
1,3,4,6 ,7	Education, Persuasion	Knowledge, beliefs about consequences, behavioural intention	Information about health consequences, credible source	1. App provides recommendations on healthy break intervals with explanation of scientific rationale and emphasize that the information is from credible sources e.g. NHS, or doctors.
19, 20	Enablement	Retrospective memory, cognitive overload, behavioural regulation	Conserve mental resources, feedback on behaviours, self-monitoring	2. Use wearable trackers to automatically monitors sitting time and App provides daily feedback to enable user to self-monitor day-to-day changes in break patterns.
2	Education	Belief about capabilities	Feedback on behaviours	3. App presents daily summary of and feedback on sit- break pattern.
5,8	Persuasion	Belief about capabilities, positive/negative affect	Focus on past success	4. The App prompts the participant, at the end of each day, to look at the App feedback on break pattern and to verbally list moments s/he has managed to take timely breaks.
21, 22	Enablement	Goal (distal/proximal), beliefs about capabilities	Goal setting (behaviour), discrepancy between current behaviour and goal, review behaviour	5. Researcher prompts the person to set goals (e.g. "I want to limit my prolonged sitting within 3 episodes per day) in the App and to review and adjust goals from time to time.
15	Incentivisation	Intention	Commitment	6. Researcher ask the person to use an "I will" statement to affirm or reaffirm a strong commitment to change the behaviour.
16,17, 18	Incentivisation	Rewards(distal/proximal) , goal (distal/proximal) reinforcement, positive affect	Social incentive, social rewards, reward approximation	7. The researcher informs the person that the App will congratulate him/her for achieving any reduction in prolonged sitting; reward is delivered by the App.
20, 21, 22	Enablement	Breaking habit, self-efficacy, implementation intention (goal accessibility)	Action Planning	8. Researcher suggests the person plan taking breaks by specifying the frequency, duration and context, including developing "if-then" rules.
11,*12 , 13, 14	Environ.Restr.	Prospective memory, cognitive overload/, *goal priming, contingencies, resources	Conserve mental resrouces, prompts/ cues, add objects to environment	9. Add objects that facilitate the performance of breaks to the environment; use the object simultaneously to cue the memory of the break action naturally associated with the object (tea break - cup)
9, 10	Training	Habits, contingencies	Habit formation	10. Researcher trains the participant to develop new responses to the introduced stimuli through repetitions.
23, 24, 25	Enablement	Social support, group conformity, organisational culture/climate	Social support (practical and general)	#11. P's could form teams and foster peer support to promote engagement with the intervention (not intentionally incorporated as part of the intervention)
26-32	Modelling	Social comparison, group norm, modelling, social support, negative affect	Demonstration of the behaviour, social comparison, information about other's approval	#12. P's could see other's sitting patterns and share strategies (not implemented in WorkMyWay technology, but could happen spontaneously and voluntarily between P's offline)

5.2.3.2 Select mode of delivery

With advances in digital technology, many of the above intervention components that would previously have required one-to-one in-person behavioural supports can be automatically tailored and remotely delivered with digital media. However, considering the development cost ("affordability" in APEASE), and the high likelihood of making changes to the intervention design after the feasibility study ("cost-effectiveness" in APEASE), it was decided that a combination of face-to-face and digital modes of delivery would be used. Specifically, those intervention components that required complex dialogue support for individualised intervention delivery (rows in yellow shade in Table 11) could be delivered, at least partly, in person by the researcher for the feasibility study.

5.3 Human-centred design of the ***WorkMyWay*** system

While the BCW is useful to guide design of intervention content, it falls in short in 2 aspects. First, it does not offer much beyond determining an overall mode of delivery (e.g. face-to-face vs. in distance via a certain digital media). However, as argued in Chapter 3, when it comes to DBCIs, the design of specific technological features and configurations of the digital technology that delivers the intervention greatly affects the fidelity and quantity of intervention delivered. Hence, the design and development of the intervention delivery system is a nontrivial matter and warrants consideration in a more granular way. Second, while the BCW framework outlines the APEASE criteria and emphasizes on making interventions relevant to the local context, it does not offer detailed guidance on ways to involve stakeholders and users and elicit their knowledge, values and preferences. Nevertheless, stakeholder involvement is undoubtedly important in building an intervention and technological system that would pass the APEASE criteria (Davis, 2009; Gram-Hansen, 2016; Mackenzie et al., 2015).

In view of the above shortcomings of the BCW, the author decides to complement the framework with the (HCD) (aka user-centred design, or UCD) methodology. Maguire (Maguire, 2001) has compiled research methods appropriate for use at different stages in the HCD cycle, from planning, understanding context of use, eliciting user requirements, to producing design solution and evaluation. Among those, the thesis author borrowed methods that could be easily embedded with other research activities to support the design and development of *WorkMyWay*. For instance, diary keeping has been suggested by Maguire (2001) as a useful HCD method for understanding the context of use and gaining a picture of how a future system can support the user. One-to-one user requirement interview is considered useful to elicit individual preferences from a range of users and generate in-depth discussions. Those 2 data elicitation techniques could be easily embedded in the behavioural diagnostic diary-probed interview study. When it comes to producing design solutions collaboratively, brainstorming, parallel design, affinity diagram and Wizard-of-Oz prototyping can be candidate methods. This final set of methods converge with the rich repertoire of workshop-based methods in HCI.

This sub-section reports the formative research on *WorkMyWay* that drew on methods or techniques from the HCD approach.

5.3.1 Requirement elicitation through diary and interview

The diary-probed interview study served the dual purposes of behavioural diagnosis (Chapter 4) and user requirement elicitation. This subsection will report the second facet of the study that draws on 2 HCD elicitation techniques, namely diary keeping (Poulson, Ashby, & Richardson, 1996) and user requirements interviews (Macaulay, 1996) to understand the context of use and user preferences.

First of all, the diary data (both photo and text) offered insights into existing routines, physical environments, and meaningful objects that had triggered breaks and that could be potentially augmented to cue more regular break behaviours (Stawarz, Rodríguez, Cox, & Blandford, 2017). According to the 291 diary entries about sedentary breaks, the most common reasons that prompted people to stand up were work-related (e.g. walk between meetings, printing) (n = 84), followed by the need to refill cups or water bottles (n=63), to go to toilet (n=53), to do chores (e.g. wash up dishes after lunch, deliver envelopes) (n=48), and to eat or snack (n=25).

Furthermore, the diary elicited user preferences on choice of objects and content of communication, with the question "what message would you like to receive from your enchanted object(s) and in what context?" on the diary form. Despite a small number of messages (n=18) submitted by participants, those messages offered design inspirations. The mostly prominent objects were vessels such as mugs and water bottles (Figure 13), which were consistent with the first finding on common triggers of breaks. The contents of those imaginary object messages fell into 3 broad categories: 1) pertained to the function of the object itself (e.g. "refill me!"); 2) reminded the participant of a personal health issues associated with prolonged sitting (e.g. "come on, stretch those legs!"); 3) provided factual information that assisted in planning of work pattern and break activities ("it's been a while since your last break. Go for a walk!" "Go to the toilet, and print those slides!").

Finally, participants discussed shortcomings of technological tools they had used for reminding breaks or tracking physical activities. These were elaborated on during interviews, along with participants' expectations and requirements for potential improvements. Key user requirements are summarised in Table 12. It is worth highlighting that all participants preferred reminders adaptive to the user's actual sitting time to those following a fixed schedule. A "snooze" function (i.e. make the reminder redelivered later) was requested by most people, so that they could retain control over when to take breaks. Tactile and visual were more broadly acceptable than audible signals as the modality of prompting breaks.

Figure 13 Photos submitted by participants to illustrate breaks

Table 12 User requirements from the diary-probed study

Existing tech tools used	User requirements for the potential improved design
Pester – a Mac software supporting customised reminders *Microsoft Outlook* – widely installed in workplace computers for calendaring and email services; some participants used it to set up break reminders *Pacer* – a smartphone app with automatic tracking and history of steps and exercises, goal setting and group-based functions. *Samsung Health* – an Android health tracking App with a home screen widget visualising step history along a timeline; also tracks sleeps and diet. *Google Fit* - A health-tracking platform for the Android OS. It aggregates info from other apps and devices to track and feedback on fitness, nutrition, sleep etc. *Apple Watch* – wearable: auto-tracks sitting, standing, and moving, visualised as 3 colour rings, and that alerts user to stand if inactive for 50 min *FitBit* – wearable + App: automatic tracking and feedback on steps, exercises and calorie burnt *App with unknown name* - for logging drinks and receiving hydration reminders	**Contextual intelligence:** • Timer should be automatically reset after a break • Smart enough to know when and where to remind me, and of what (e.g. suggest break activities based on the context and learning of my past behaviours, like usual coffee at 3 pm) • Integration with Google Calendar/Ft, location, and all threaded together **Support user agency and autonomy:** • I should have agency over when to take breaks • I should be able to opt-out of the reminder function on certain days and occasions • Don't lock up screen when I need to work **Manner of communication** • perseverant yet flexible: allow user to "snooze" for several times • factual & informational: display the sitting time • requested rather than pushed: always there, doesn't force you to open it but you can choose when to view messages • **Conflicting views:** gentle, soft tone of voice ("maybe you WANNA take a break") **vs.** forceful, telling me off, making me guilty **Historical and social comparison:** • visual feedback on my break pattern is very revealing and allows me to compare between days and set target for myself • the comparison with others is interesting but does not necessarily motivate everyone; it could also be interpreted as employer's surveillance and sabotage behaviour change **Perceived/desired object qualities:** • credible and authoritative so as to help me justify myself because I'm being told to take a break • **Conflicting views:** functional and utilitarian, non-gimmicky **vs.** enchanted anthropomorphic object **Modalities of communication:** • Tactile/visual: acceptable to most people • **Conflicting views:** Audible (e.g. beep, music) prompts were most noticeable but unacceptable in shared offices **Choice of objects**: • Most common: mug, water bottle • Also mentioned: existing gadgets e.g. PC, watch • Miscellaneous: pen pot, rubber duck, plant

5.3.2 Synthesis of findings from prior human-centred design research

The synthesis of design-related findings as part of the scoping review (Chapter 3) was essentially a summary of design knowledge accumulated with prior HCD research. Hence, the design implications are repeated here:

1. The intervention could advantageously employ the technological feature of Automated Tailored Feedback on sedentary behaviours as they are highly valued and liked by participants/users in previous studies

2. The design should consider different forms of feedback and their respective purposes, ranging from a detailed lifelog of activity episodes for reflection and education, through "at-a-glance" summative data for real-time awareness of behaviour and consequences of behaviour, to a straightforward break countdown for actionable information.

3. Unlike feedback delivery, the delivery of prompts does not necessarily require rich media; the timeliness matters more than the textual content of the message; prompting the user after every 60 minutes of sitting seems most acceptable, although a variable interval adaptive to the user's past compliance to prompts would be even more desirable.

4. To support sustainable behaviour change, prompts for breaks should not annoy users; there is consistent evidence for positive user evaluations of "physical", ambient feedback (by changing the appearance of the physical environment) delivered with novel screenless media.

5.3.3 Stakeholder design workshop

5.3.3.1 Background and aims

While the diary-probed interview study elicited user design requirements, it did not consider managers' or work health specialists' perspectives. Although it had been decided that the intervention would be initially positioned as a potential consumer product that individuals could adopt for their own health, it was nonetheless still important to consider the organisational constraints imposed on individual use. The bottom line was that organisational gatekeepers (e.g. line managers) would not forbid or frown upon employee's personal decision to use the intervention.

At the time, the EPSRC-funded Balance Network launched a funding call (EPSRC, 2015) to support events that "link academics with business, policy and user groups interested in the role that digital technologies are playing in (re)shaping our work and home lives". The author applied for the funding to conduct a stakeholder design workshop and successfully secured it. The objectives of this workshop were:

1. to engage potential stakeholders (e.g. managers, experts/consultants on work health and organisational science, developer, and end users/recipients) of the proposed intervention to review and validate (or refine) the initial set of requirements,
2. to shape the interaction design to the needs of target organisations (e.g. university and several other potentially interested organisations)
3. to solicit buy-into and commitment to the potential intervention

The half-day workshop was attended by 8 participants (Figure 14) representing a variety of organisations (e.g. start-up, large private company, higher education), occupations (e.g. self-employed work health consultants, industry scientists, doctoral researchers and senior lecturers) and expertise (e.g. occupational health, organisational communication, sociology and organisational sciences, architecture, physics, interaction design). They contributed to the workshop on the basis of both their personal experience of working within organisations and their expertise in technology/intervention design or a relevant problem domain (e.g. work health or organisational management).

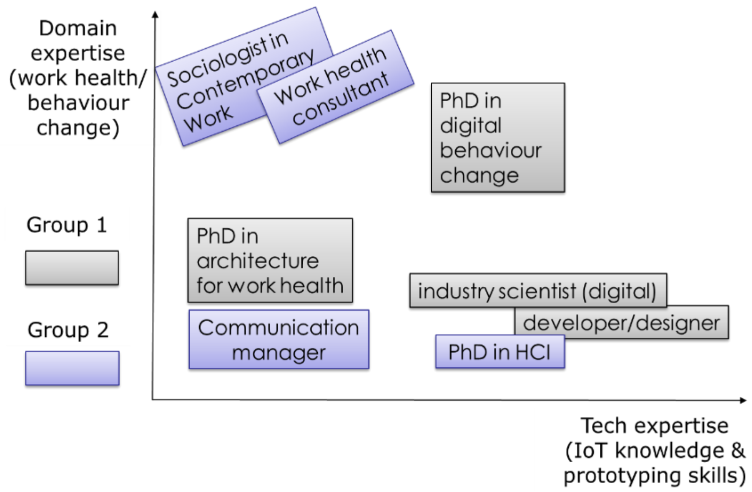

Figure 14 Expertise of participants split into two design groups

5.3.3.2 *Tools, procedures and outcomes*

The workshop was jointly designed and facilitated by the author and Roma Patel, a digital artist and a PhD student at the Horizon CDT. The tools and methods had been piloted with 10 PhD attendants at the Digital Economy Network (DEN) summer school in Newcastle several months before this formal workshop reported here. Improvements had been made based on feedback and reflection following the pilot workshop. The formal workshop comprised 4 activities. All resulting artefacts (completed worksheets, prototypes) were photographed and the final group presentations were video recorded with participants' consents.

Activity 1 - about me and my workstyle

We asked each participant to first write on a post-it note his/her name, organisation, job title and work activity examples (e.g. communication, project management, research), and then self-identify his/her own workstyle. We had prepared 4 graphs illustrating 4 different workstyles (i.e. work break pattern) on a flipchart standing in the front of the room. Each participant would then come to the front, introduce themselves and stick the note to the graph illustrative of his/her own workstyle(s) (Figure 15). These 4 patterns reflected the main architypes observed in the diary-probed interview study. This activity was intended as an ice breaker to get people to reflect on their workstyles and as a tool to validate workstyles identified from the previous study.

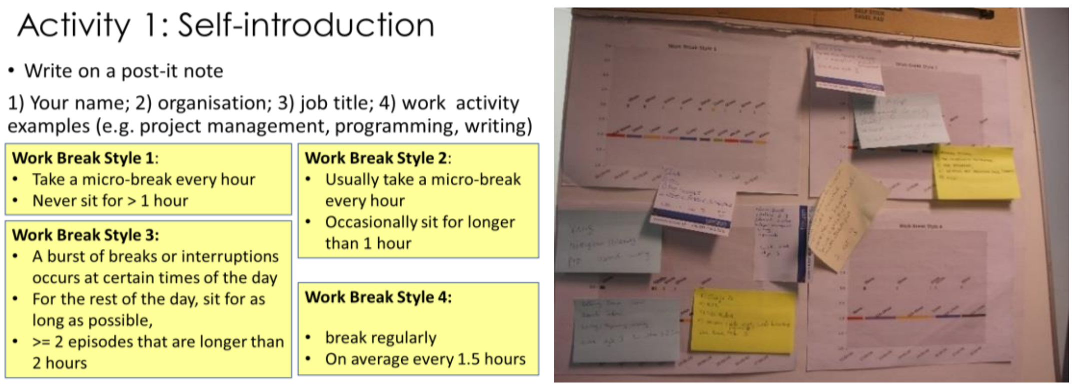

Figure 15 Ice-breaking activity: self-reflection on work break styles

Results

All participants could relate themselves to at least one of these workstyles, suggesting the good coverage of common workstyles with those archetypes. Moreover, workstyle 3 was identified by most participants as their patterns, where frequent interruptions at certain times of a workday were commonly accompanied by long sitting episodes during the rest of the day, corroborating Theme 3 reported in Chapter 4, and illustrating the importance of considering cognitive activities when designing reminders for physical breaks.

Activity 2 – requirement review (individual worksheet)

Then the author gave a presentation on the COM-B model and behavioural diagnostic results from the diary-probed interview study. The individual worksheet (Appendix 8) that followed the presentation allowed participants to rate the behavioural determinants in terms of "to what extent does this reflect what you've observe in your workplace?" and "how important do you think this factor is in determining micro-break behaviour? from 1 (not at all) to 5 (very much). After giving ratings and comments privately, participants were given an opportunity to share their own experience in a big group and to build a shared understanding of the problem space.

This was the point when the author showed the participants the list of candidate intervention functions and BCTs informed by the behavioural diagnosis, and a proposed technological system (Figure 16) to deliver those BCTs. Some commercially available smart cups or cup accessories were passed around. The aim of this activity was to give participants a more solid idea of how embedded sensing, data processing, wireless network and different digital interfaces could fit altogether, and what the system was capable of doing. Participants were encouraged to ask questions about the technology and intervention, give feedback on the social acceptability and discuss potential deployment issues of using those smart objects in office settings.

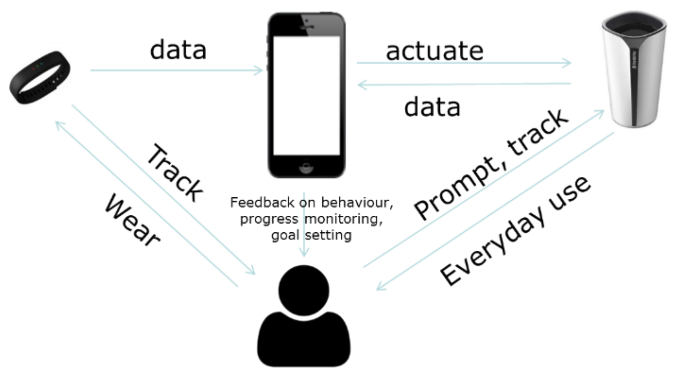

Figure 16 proposed system design presented to participants

Results

The individual worksheet responses were mostly consistent with the behavioural diagnostic results. Participants were receptive to the proposed intervention and technology, and raised questions mostly concerning technical details (e.g. how can the cup know if a break is taken if the user doesn't not take the cup with him/her during the break?).

The discussion validated the majority of design requirements elicited in the first study, such as "support user agency and autonomy", "contextual awareness". In addition, "personalisation" (i.e. automatically adapted to one's calendar and past behaviour) and "customisation" (i.e. user having the option to turn on/off or change functions) were highlighted as 2 desirable features. On a related note, participants suggested the intervention needed to be tailored to different organisational cultures. The work consultants who worked across different organisations raised the concern that the proposed break intervention would not fit into the work of people with front-facing jobs; in addition, she mentioned that, for most organisations, managers would demand proof that the intervention was effective to increase productivity before introducing it to staff members (which will be discussed as an implication for future research in Chapter 7, Section 7.3). Finally, participants were concerned that using the visual aspect of a cup could potentially prime people to consume much more coffee and they suggested using a water bottle as an alternative.

Activity 3 – group ideation

After reviewing and validating the theory-based intervention requirements, participants were split into 2 groups to ideate system features by completing a group worksheet (Appendix 9). Although the workshop had an underlying theme of encouraging regular breaks to reduce prolonged sitting at work, participants were encouraged to explore and design for broader issues related to taking breaks, such as interruption management, co-worker interactions and stress management.

As it was challenging to translate theory-informed requirements into system design, this process was supported by a deck of 25 Persuasive IoT Ideation Cards (including 3 blank cards for card users to specify other opportunities they can think of) (Figure 17). The author had specially designed the cards for this workshop. The categories and contents were inspired by previous IoT decks (Chen, 2011), persuasive design frameworks (Oinas-

Kukkonen & Harjumaa, 2009) and the BCT Taxonomy (Michie et al., 2013). The deck was meant to stimulate people to think about how design opportunities arising from sensing technologies, social interactions/influences and physical characteristics of everyday objects, and to enable mutual learning between group members. Participants were encouraged to ask the tech-savvy person in the group to explain contents on the "sensing opportunity" cards e.g. technological capabilities and constraints.

Results

Appendix 10 contains some completed worksheets, illustrating how the cards had been used to ideate system features, which were prototyped and showcased in the next activity. According to photographs (Appendix 10.) and the worksheet, Group 1 had considered the following cards: "social comparison", "normative influence", "self states", "cooperation", "activity tracker", "active location sensing", "gestureability (affordance)", "glanceability" and "reward" during ideation; Group 2 had considered "people states", "cooperation", "activity tracker", "active location sensing", "weight sensor", "psychophysiological sensing", "glanceability", "gestureability (affordance)", "reward", "tangible manipulation", "peripheral interaction", and "remember".

Figure 17 Persuasive IoT ideation cards

Activity 4 – prototyping the user journey

Built on the previous activity, each group was asked to prototype specifics of user interfaces and interactions. The co-facilitator, Roma Patel, introduced concepts and techniques for low-fidelity prototyping of smart objects. Each group was provided with a range of loose materials, some *Lego* mugs and *LittleBits* (LittleBits Electronics Inc., US). The *LittleBits* are educational kits with modular electronics that can snap together with small magnets to make circuits. As *LittleBits* are compatible with *Lego*s (can be attached *Lego* bricks), participants could tailor-make their own smart mug by attaching *LittleBits* electronics to the Lego mugs (Figure 18). This allowed participants to prototype and try different modalities of interactions (e.g. light, vibration, sound) with a potential smart mug. Participants were encouraged to undertake what we called "bodystorming", which meant an embodied walk-through of an imaginary interactive system as if it had existed, to get a more realistic feeling of the user experience.

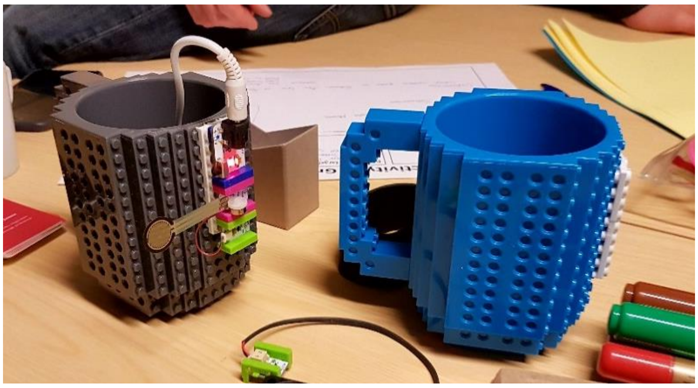

Figure 18 Smart mug prototype made with *Lego* mugs and *LittleBits* electronics

At the completion of the activity, each group showcased and reported back on their design ideas and prototypes, with the other group asking questions and suggesting improvements on the design.

Results

Group 1 were designing for open plan offices where several individuals usually brought back drinks for the rest of their office/team, so that the office mates could remain sitting and working for longer without the need to leaving their seats. Group 1 came up with an idea centred on making use of this existing group practice and social influences on behaviours (Figure 19). In their design, each individual would have a smart mug that was linked to the individual's wristband, which worked together as identifiable check-in devices. A system that connected all mugs together would figure out who was in the most need for a break in the office and vibrate his/her mug. The person being prompted would then need to check in at a specific point (e.g. kitchen) and bring back drinks for office mates. By doing so, one could move himself/herself straight to the top of the list (the one at the bottom of the list gets prompted). One could also take a break every now and then without moving his/her mug, to stay in the middle range and avoid being prompted, as general physical activity breaks would be captured with the wearable tracker. Another key element of the design was the introduction of between-team competition with a dashboard display in a common area. The dashboard would show the state of healthiness of each office in green, yellow or red colours based on aggregate data of all office members, without giving away personal information or individual behavioural details.


Figure 19 Design idea generated by Group 1

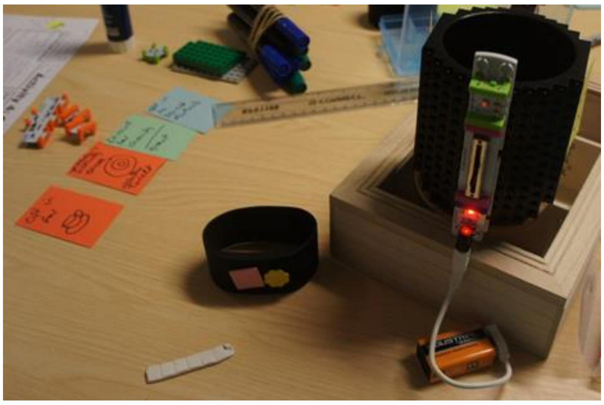


Figure 20 Design idea generated by Group 2

In contrast, Group 2's design idea (Figure 20) demonstrated a focus on the individuals, by protecting privacy, supporting personalisation and user autonomy and providing positive reinforcement. They presented a prototype of a mug with an attached ambient display tailored to individual preferences, for example, a picture of one's dog gradually showing up, or a LED lighting up, to suggest to the user, "maybe you can take a break and walk a dog", in a gentle and entertaining way. 2 buttons were designed on the mug. One should allow the user to temporarily disable all reminders during meetings. The other was a "snooze" button allowing the user to postpone the visual reminder for up to 3 times, after which a vibratory reminder would be triggered on one's wristband. To disable the wrist reminder, the user would need to either take a break or shake the arm very vigorously. Group 2 expected this design to influence work break culture in a scenario where everyone started shaking their arms in a prolonged meeting. Finally, they also presented a paper prototype for a dashboard App that was intended to provide feedback on how often the user snoozed the reminders versus took breaks promptly on the previous day. The App also rewarded breaks with virtual points that could lead to charitable donations in the user's name. Group 2 suggested that the data should be kept private online, although users could choose to share their App screens with friends offline to foster competitions and opt in for the "social break" function to make their statuses visible to other users of the App. However, the system should respect the freedom and privacy of those who preferred taking breaks on their own without being discerned by others. Group 2 also did not want the exact sitting time to be displayed on the wristband or cup.

2 groups discussed on the choice of device and objects for delivery of information and persuasion. The use of a dog image and the mug to prompt breaks was spoken of positively among participants as these were associated with the break activity and had a potential priming effect. They also compared and contrasted tracking and prompting breaks with a smart vibratory chair versus a wristband. Compared with a chair, a wrist-worn tracker was more portable and hence suitable for modern office workers; unlike a chair, a wristband could also track steps and provide feedback focused on positive reinforcement; thirdly, Group 2 specifically highlighted the fact that a vibrating wristband was also less disturbing to others than a vibrating chair.

5.3.3.3 Design inspirations

Apart from validating the initial set of design requirements, a number of design inspirations have arisen following the workshop:

1. Persuasive system designs need to strike a balance between conserving privacy and gaining leverage from social influences. A potentially viable approach is to utilise the digitally augmented physical artefact to display "shareable" information while using the App for private feedback; the ability to physically manipulate (e.g. turn around or put in a drawer) the objects to conceal information gives the user more control of who to share the information with.
2. The progress of reducing sedentary behaviour can be gamified and rewarded with virtual points, affirmative words or social recognition. The rewards should be carefully designed to strengthen the user's intrinsic motivation to be both healthier and more productive at work.
3. It would be useful for the interface to suggest not only the time for a break, but also potential activities to engage during a break (e.g. refill one's cup, bring drinks for others, walk one's dog).

5.4 Technical design, specification and implementation

5.4.1 Technology learning and prototyping

To get hands-on experience in collecting and analysing sensor data, the author undertook the module G54UBI Ubiquitous Computing at the School of Computer Science. As part of the individual assessment, the author decided to prototype parts of the proposed sedentary behaviour intervention technology on a *Raspberry Pi* together with the *GrovePi*, which was a set of development kit provided in the module for prototyping embedded sensing and interactive systems. As a result, the author built a functional prototype, called the "Omniscient Mug", which featured an anthropomorphic mug character sending context-aware messages based on the user's sitting, drinking and physical manipulation of the mug (Figure 21).

It should be noted that the purpose of the prototyping activity was not to determine the specifics of the user interactions or interfaces to deliver the proposed intervention. The choice of the output interface and modality of communication was inevitably constrained by the output modules available in the *GrovePi* kit. Instead, the purpose was to familiarise the author with capabilities and limitations of different sensors. Over the process, the author learned about principles for designing sensor-based interactions (Benford et al., 2005), and fusing data from multiple sensors to generate just-in-time persuasive information (Intille, 2004). One of the key lessons learned was the limitation of sensors and the mismatch between the sensed, expected and desired movements. For instance, an algorithm might not be 100% accurate in differentiating activity and inactivity in all contexts; a user might perform unexpected behaviour to "fool" the system. Such situations posed challenges for delivering context-aware and meaningful information at the right time. However, they could also be considered opportunities to encourage physical activity – rather than punishing the user for fooling the system, the system could reward and gamify physically demanding efforts to fool the system.

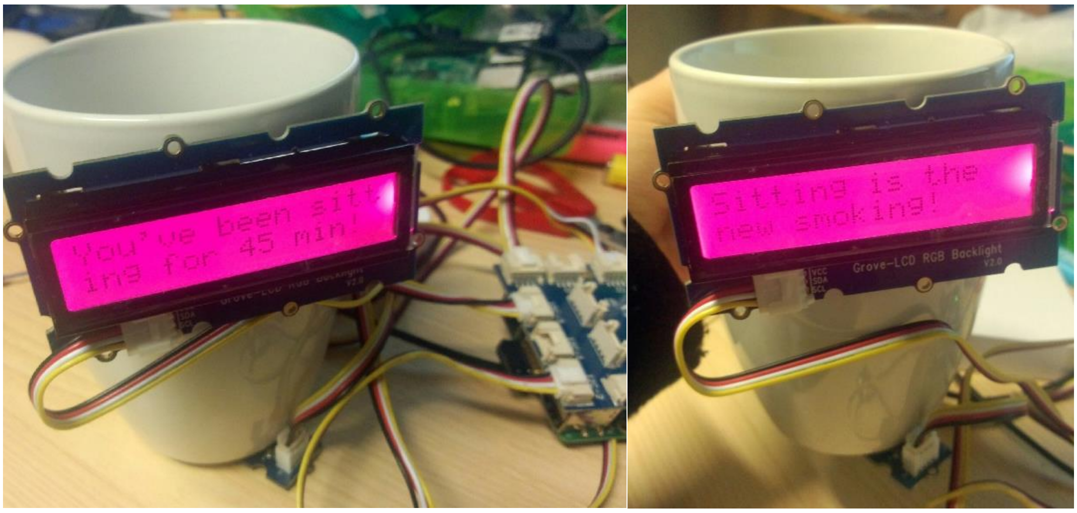

Figure 21 The "Omniscient Mug" prototype when sitting time reaches 30 minutes, it will be displayed with pink backlight as a subtle reminder (left). Whenever the mug is moved, indicating the user paying attention to the mug, the LCD will further light up and display a message with fear appeal (right).

5.4.2 Technology audit

Apart from hands-on learning, the author kept up to date with emerging IoT technologies in the industry and reached out to technical experts in the Mixed Reality Lab, with the aim to develop a feasible implementation plan for the doctoral project.

Based on the intervention components identified in previous steps, the following candidate technologies were identified as being relevant – a wearable sensor that automatically tracks the user's sitting time, a digitally augmented water bottle or cup with some simple interface that delivers minimal information necessary for creating in-situ awareness of sitting time, and a multimedia interface (could be screen-based or non-screen-based) that provides more detailed feedback on sitting patterns; some wireless communication infrastructure is also required for transmitting data between these interfaces or devices.

An immediate thought was to adopt a commercially available activity tracking device and IoT cup to save development time and cost. However, this was later found infeasible, because very few IoT products available in the market at the time came with Application Programming Interfaces (APIs) to allow third-party developers to stream raw data and actuate the output modules from the IoT cup device in real time or near real time. Neither was it feasible to make an electronic board from scratch, given the author's limited knowledge of electronics and access to support from experts in this domain. Platforms like Raspberry Pi were too bulky to be fitted into a cup or wrist tracking device. Hence, along a continuum of implementation choices (Figure 22), the author opted for somewhere in the middle: production-ready development boards.

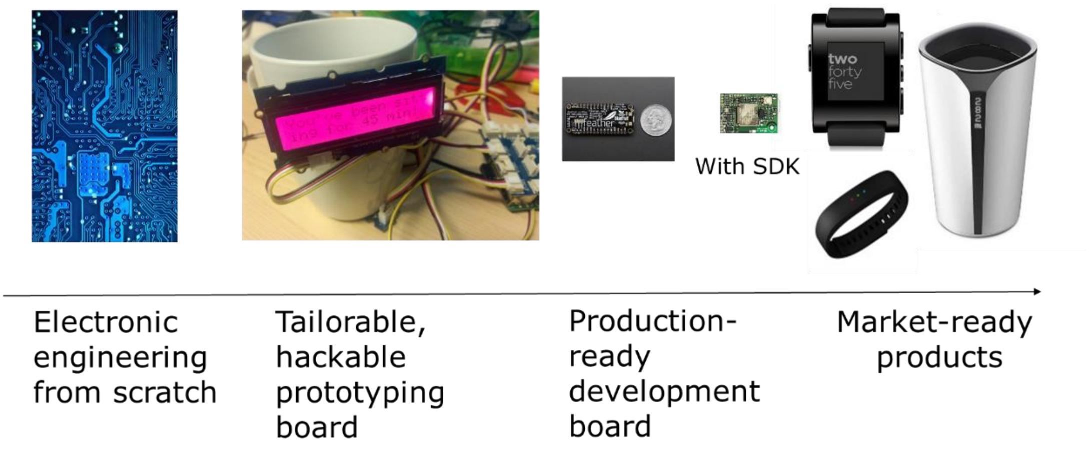

Figure 22 A continuum of implementation choices – left end: highly tailorable, but requires expertise in electronic engineering and product design; right end: fine-finished look but less tailorable or hackable

The requirements for the boards are i) compact enough to be worn by the user and attached to or embedded in a cup; ii) sufficient computational power for running simple step detection algorithms and local storage space for caching timestamped step events for at least 2 hours; iii) programmable output modules or controllable General-Purpose Input/Output (GPIO) pins; iv) low power consumption with battery lasting for at least 8 hours without charging; v) wireless connectivity.

For the wireless data transmission, there exist many different technologies and protocols. Some are optimized for relatively infrequent or small-packet data exchanges at low data-rates (e.g. Zigbee, Z-Wave, LPWAN) and are hence unsuitable for synchronising frequently sampled movement data between devices in real time; in addition, some (Zigbee and Z-Wave) require special hubs for relaying the data to a computing device or the cloud because the modules are not built into most consumer computing devices (e.g. PC, smartphones); the 10 cm range of NFC makes it unsuitable for frequent exchanges of data between devices separate from each other; directly uploading sensor data to the server or computing device via cellular network or Wi-Fi could drain a small size battery very quickly. Therefore, Bluetooth Low Energy (BLE) was selected because its transmission range, data rates and power consumption are suitable for the project.

Because of the BLE setup, it was decided a smartphone App was best suited for the role of a central device that relays the sensor data collected with the peripheral devices to the server database, provides detailed on-screen feedback, actuates the output module on the cup device and supports user customization. Hence, a board that comes with an Android/iOS Software Development Kit (SDK) would be even more preferred.

After researching and comparing features of different platforms in relation to the above requirements, the author found 2 platforms, namely the *MetaWear* RG (MbientLab Inc., US) and the Adafruit Feather Bluefruit LE (Adafruit, US), to be fit for the purpose.

5.4.3 Technical design and implementation

The authors combined 4 sets of requirements into a specification document (Appendix 11): i). theory-informed requirements in terms of BCTs, ii). user requirements in terms of desirable interactive features of the technological mode of delivery, iii). technical requirements arising from audit and prototyping, and iv). research requirements for data synchronisation and processing, and administration functions etc.

The document was then circulated with developers in the Mixed Reality Lab and Horizon Digital Economy Research Institute, to solicit advice, help and potential collaboration. Dominic Price (hereinafter referred to as "the developer") from Horizon kindly volunteered to develop the smartphone Application in his spare time. The developer and the author met and exchanged emails regularly to discuss the requirements and finalise the specification document.

It was also decided during this stage that intervention components related to interpersonal and group influences (e.g. social support, competition, cooperation, demonstration of the behaviour by managers and workplace champions), calendar integration and personalised image on vessel would not be implemented in the system. First, both the diary-probed interview study and the stakeholder workshop suggested that conversations and competitions would be triggered by the tracking and feedback and occur offline in offices naturally, without the need to explicitly foster competition or cooperation online. Second, the integration of calendar data, social functions and personalised reminders would, to a great extent, complicate the architecture design and increase development difficulty. Third, the social function and calendar integration also add to the ethical controversies, making the system seem like a tool for employers to exercise surveillance and control on staff members; the sharing of data regarding break patterns with co-workers might encourage some to sit for longer, as suggested by participant quotes from the diary-probed interview study (Chapter 4).

5.4.3.1 System architecture, platform and APIs

Based on the technology audit, the author initially proposed to use the *MetaWear* RG (MbientLab Inc., US) (Figure 23. left) for the wrist tracking device and the *Adafruit Feather Bluefruit* LE with *Adafruit* NeoPixel RGB LED Strip (Adafruit, US) (Figure 23 right) for the cup reminder device, as the latter could support more sophisticated designs of LED patterns.

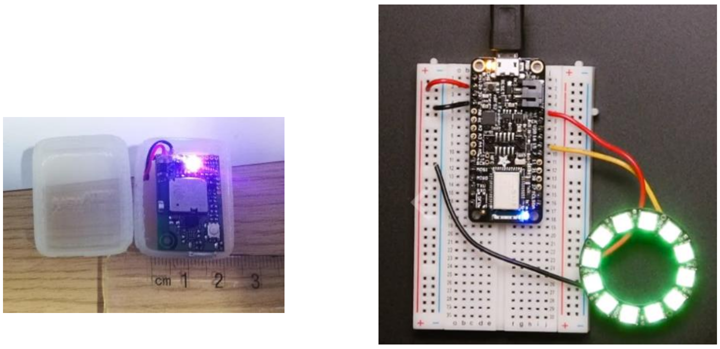

Figure 23 Proposed development boards for implementing the delivery system:

MetaWear RG board (left), measures 26mm x 17mm x 2.5 mm, built-in BLE, 6-axis accelerometer/gyroscope, temperature sensor, a 3-colour LED, a rechargeable lithium battery, and an optional vibrating motor; *Adafruit Feather Bluefruit* (right), measures 51mm x 23mm x 8mm, 19 GPIO pins connectable to external sensing or output modules (e.g. LED strip, vibrating motor), built-in USB battery connector/charger.

However, the developer suggested using the *MetaWear* board for both devices and building an Android App with the *MetaWear* Android SDK only, to ease the development process. As the goal was to build a minimum viable product to test the feasibility of delivering reminders from an object-based interface, the author adopted the suggestion and refined the specification document (Appendix 11) based on the *MetaWear* specs.

Figure 24 illustrates the system architecture and APIs used. A diagram illustrating how data and commands flow from one system component to another in real-time tracking and processing is in Appendix 12.

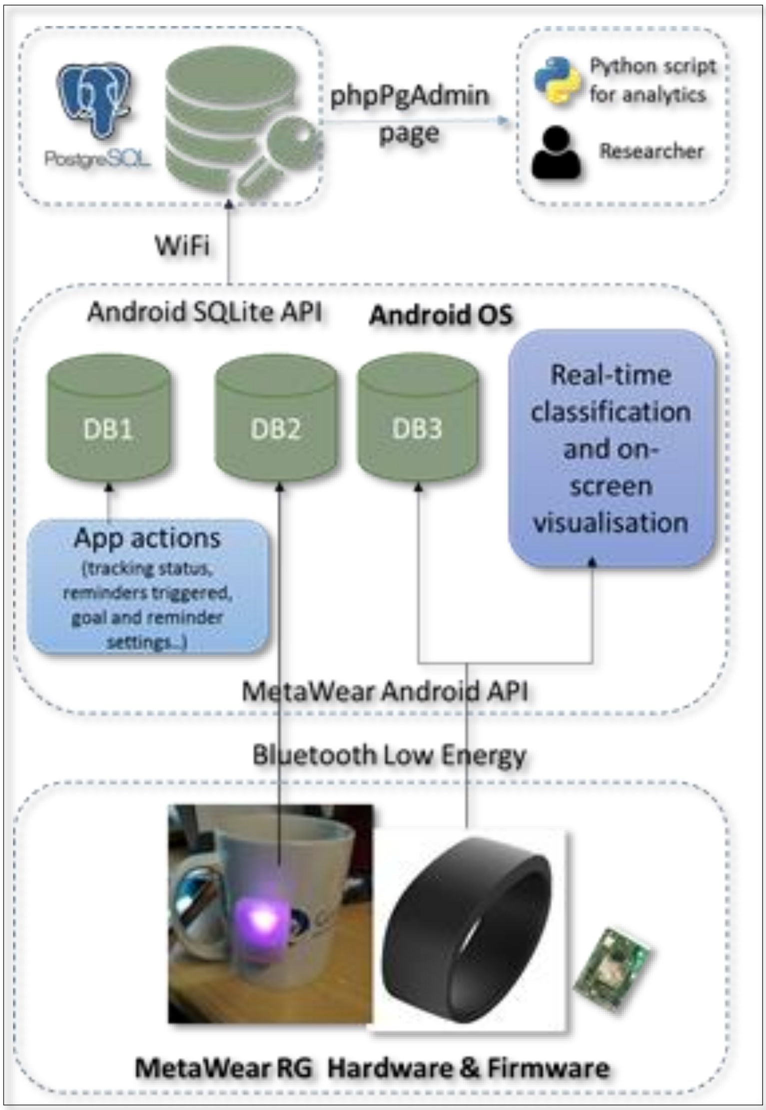

Figure 24 System architecture for *WorkMyWay*

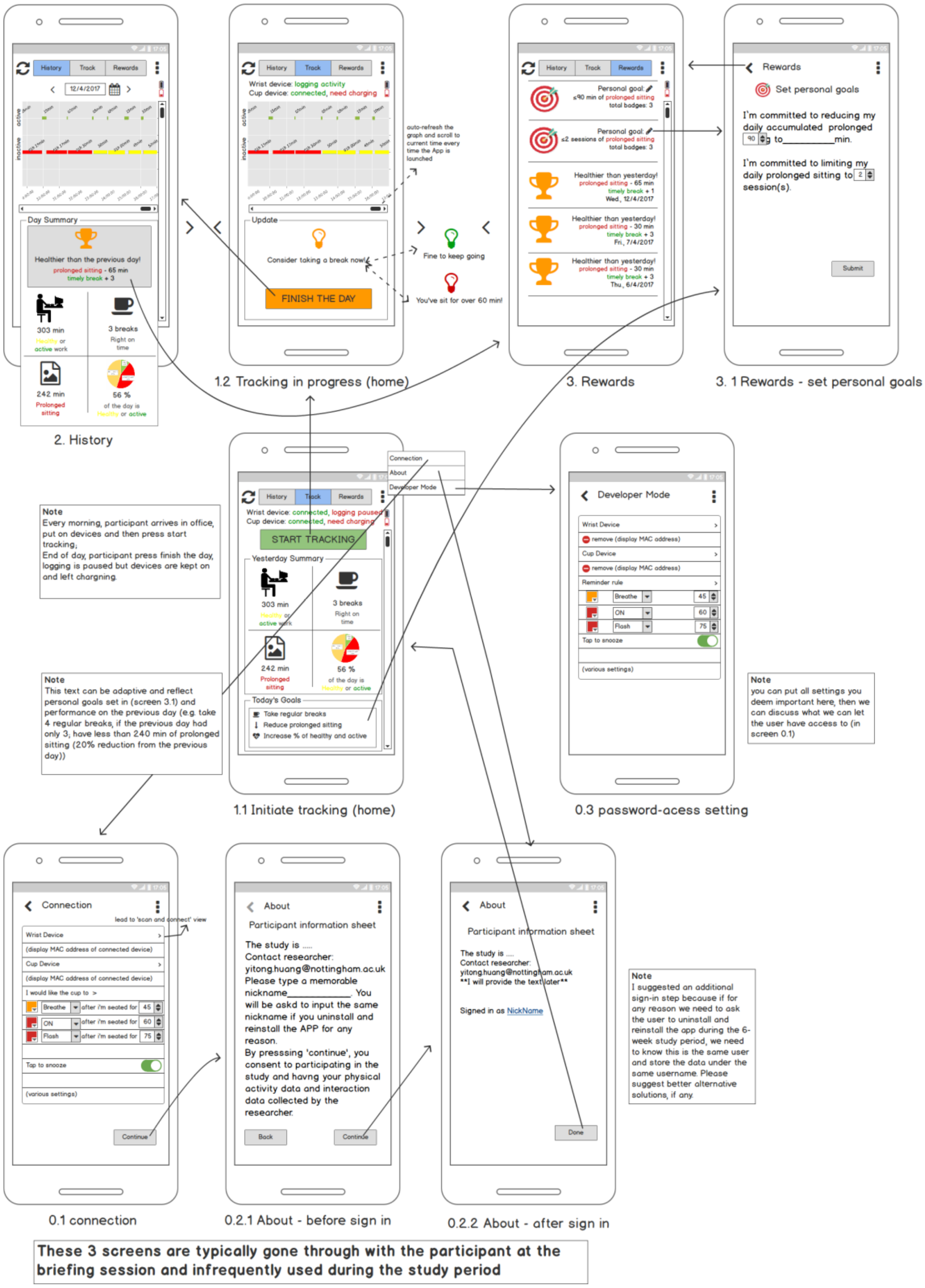

Figure 25 Wireframes for the Android App

(*This is to illustrate the interaction flow. For clearer text content, see Figure 28 – screenshots of the implemented App).

5.4.3.2 App structure and interface

After finalising the specifications document, the author designed the information architecture (e.g. layout and navigation) for the App (Figure 25), based on Android guides for User Interface and Navigation design (Google, 2017). Tabs were chosen for the lateral navigation between 3 sibling sections, namely "track", "history" and "rewards", which were expected to be used most frequently. The infrequently used and discrete options ("about", "setting", "developer setting") were accessible from a drop-down menu indicated by 3 dots at the top right corner in the App.

5.4.3.3 Activity classification algorithm design

While the developer was working the Android development, the author was developing the activity detection algorithm. First, the author reviewed epidemiological and engineering literature on accelerometer-based sedentary behaviour measurement, summarised pros and cons of different technical approaches and implications for research. Then she conducted structured and unstructured data collection sessions and designed a classification algorithm. This subsection summarises the decision process and resultant solution.

In the literature, classification of physical activity using motion sensors has been predominantly based on processed accelerometer data in the form of **counts per epoch** (CPE) rather than raw axial or acceleration vector magnitude. This method involves 3 key technical decisions – the calculation of "counts", the optimal epoch length and cut-off points.

The *MetaWear* API supports streaming of both raw tri-axial accelerometer readings and processed "counts". Although the *MetaWear* documentation refers to the latter as "step counts", initial testing found the figure always far exceeded actual step count. It is likely that this "step count" in *MetaWear* API is equivalent to what other technical documents have referred to as "accelerometer count". However, the process of deriving "count" from raw accelerometer tri-axial data is mostly ambiguous and proprietary. One of the possible techniques involves applying a bandpass filter to the acceleration vector magnitude and then converting the signal into a numerical output value called the CPE, measured as the count of peaks detected or zero-crossings during a specified period of time (Freedson, Melanson, & Sirard, 1998). Despite the ambiguity of the underlying technique used by the manufacturer to calculate the count, CPE can be considered a good indicator of activity intensity.

Cut-off points could then be applied to the CPE value to classify activities into sedentary behaviour (SB), light physical activity (LPA), and moderate-to-vigorous physical activity. There is no agreed upon cut-off points, which also vary according to the placement of the accelerometer (e.g. wrist-, waist-, thigh-, or hip-mounted), type of calibration activity used, age and maturational stage, sex, fitness level, leg length, and body composition of the sample (Boerema, Essink, Tönis, van Velsen, & Hermens, 2015). The cut-off points for wrist-worn accelerometer are presumably much higher, given the higher mobility of wrist during sedentary time and more noise in the data. Several studies have established cut-off points for wrist-worn accelerometer CPE (Troiano, McClain, Brychta, & Chen, 2014) with different devices (e.g. *ActiGraph*, the *Actical* accelerometer, the *Actiwatch, GENEActiv*). Hence, the author would need to derive cut-off points for the relatively new *MetaWear* device with empirical data.

As for epoch length, a 60-second epoch has been widely used to measure activity in adults (Cain, Conway, Adams, Husak, & Sallis, 2013); however, a shorter epoch would be needed to reflect the sporadic nature of LPA that intersperses SB in office work. A 10-second, 15-second and 60-second epoch length has been used in measuring PA in office workers in (Jancey et al., 2014), (Boerema et al., 2015) and (Donath et al., 2015) respectively. The author opted for the 15-second epoch length.

The author conducted a series of structured data collection sessions covering activities like sitting while typing, sitting while writing, sitting while talking with hand gesture, sitting while torso twisting, standing up, walking for 5 steps, walking around the building blocks etc. The data revealed that most sitting activities featured a CPE of less than 5, with occasionally epochs of 5~10 CPE (e.g. torso wrist); walking continuously featured a CPE of 23 ~30; standing activities away from seat (e.g. standing up to open the window blinds in the same room) could have an CPE between 10 to 25 CPE. The author decided that the system should pick up 2 types of events that could signify the start of different types of movement breaks – a burst of high intensity movement (CPE>25) that signifies walking to a different room, and a continued period of mild movement (CPE>12) that potentially means doing chores in the room.

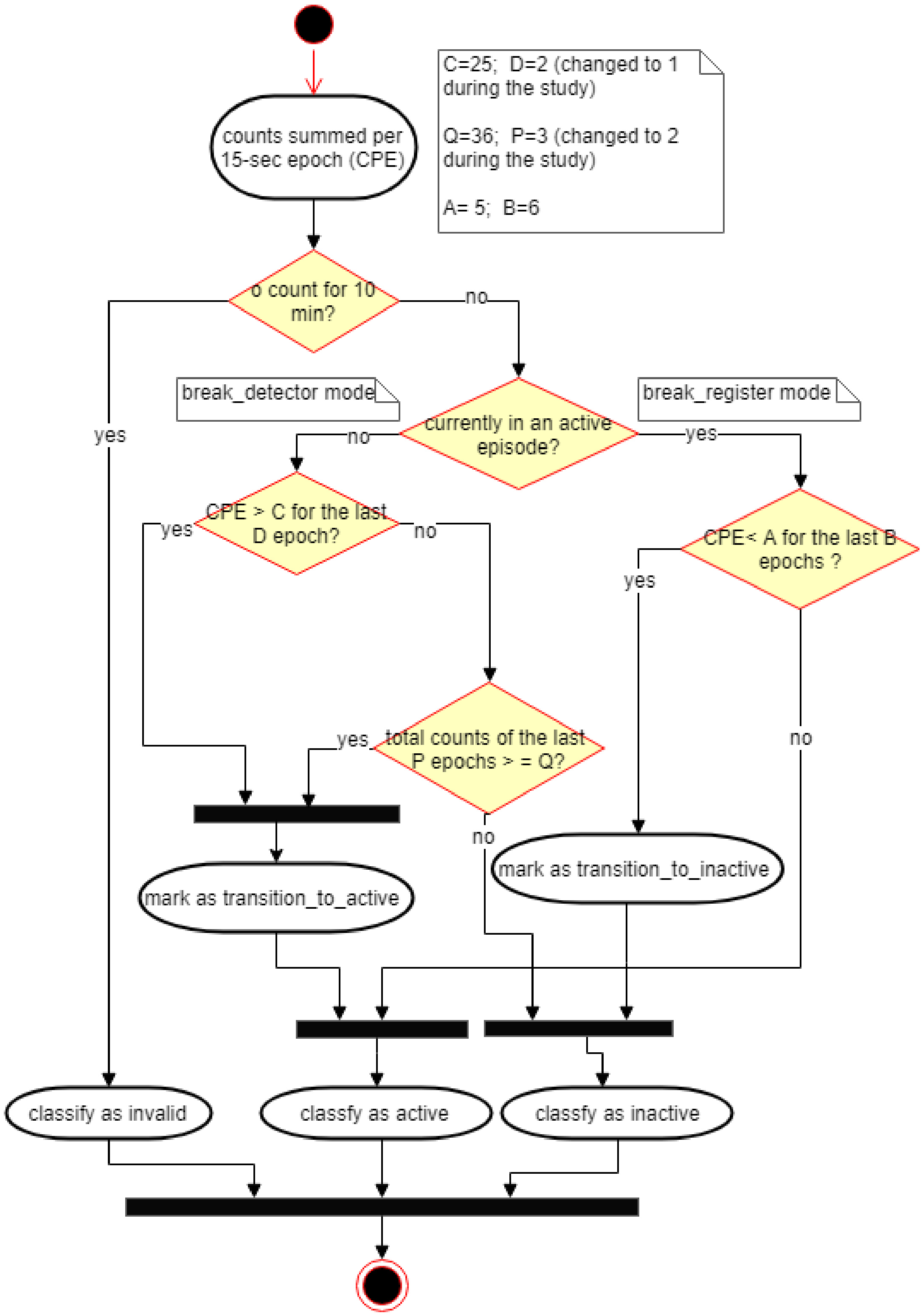

Figure 26 Activity diagram illustrating the classification rules

Hence, the author designed an algorithm (Figure 26.) that differentiates SB and breaks based on a combination of activity intensity (i.e. CPE cut-off points, parameter C, Q, A in Figure 26) and temporality (i.e. number of continuous epochs with CPEs exceeding the cut-off points, parameter D, P, B in Figure 26). Moreover, the algorithm featured a break detection mode and a break register mode, used different cut-off points for different modes. This was to reduce frequent transitions between SB and breaks in the data that were most likely noises introduced by sporadic hand movements (e.g. fidget, gesture) while sitting. The resulting algorithm classified workday time into active and inactive (SB) episodes.

The author acknowledged the existence of activity classification algorithms that are more sophisticated than the author's "quick-and-dirty" method. However, the key point here was not to make a perfectly accurate detection algorithm; it was more about capturing what the user and the intervention designer wanted to recognize as "active breaks". Hence, the parameters A, B, C, D, P, Q in the algorithm were made to be changeable in a password-access menu in the App. In this way, the researcher had the flexibility in making the break detector more or less sensitive for different users/participants at any point during the study. The initial parameter values were determined based on visual inspections of test data. D was changed from 2 to 1 very early on in the study, to make the system more sensitive in detecting walking breaks; P was changed from 3 to 2 during the study, to make it less sensitive in detecting within-room chores, which most participants did not want to consider as breaks.

5.4.3.4 Database specification

The author had planned research data analysis at the same time of designing the system, and made requirements that the following data tables be accessible from the server in either CSV or SQL format:

1. Connection_status: Timestamps, connection_status (Bool: True or False), userID, Lite (Bool: True or False)
2. Tracking_status: Timestamps, tracking_status (Bool: True or False), userID, Lite (Bool: True or False)
3. Count_reading: Timestamps, deviceID (int: 0 (wrist) or 1 (cup)), userID, Lite (Bool: True or False)
4. Alert_table (reminders): Timestamp, alertType (Int: 45, 55, 60, -1(turned off as user takes a break)), delivered (Bool: True or False)
5. Goal_setting_record: goal, timestamp of user updating the goal

6. Reminder_setting_record: first/second/third reminder pattern, threshold (minutes), timestamp of update

5.4.3.5 *Casing design*

While this PhD is not one on industrial or product design, the casing design of the smart cup can greatly affect the user experience of the technology and fidelity of delivery for the intervention. Therefore, it is worth briefly mentioning the design decision. Appendix 13 details the 5 different design solutions proposed by the author. Solution #3 that features a sensor case attachable to any water bottle or mug was chosen, because of its broad suitability (for both hot and cold beverage consumers), reusability (can be taken off and stuck to another vessel for the next participant without hygiene problems), and flexibility (can be removed from the cup/bottle during meeting, or for charging).

5.5 Conclusion

The resulting intervention, *WorkMyWay*, draws on the BCTs of information about health consequences, credible sources, conserve mental resources, feedback on behaviours, self-monitoring, focus on past success, commitment*, goal setting*, discrepancy between current behaviour and goal*, review behaviour goals*, action planning*, prompts and cues, habit formation*, social incentives, social rewards, and reward approximation. The BCTs with * are delivered via a combination of the technological system and face-to-face sessions.

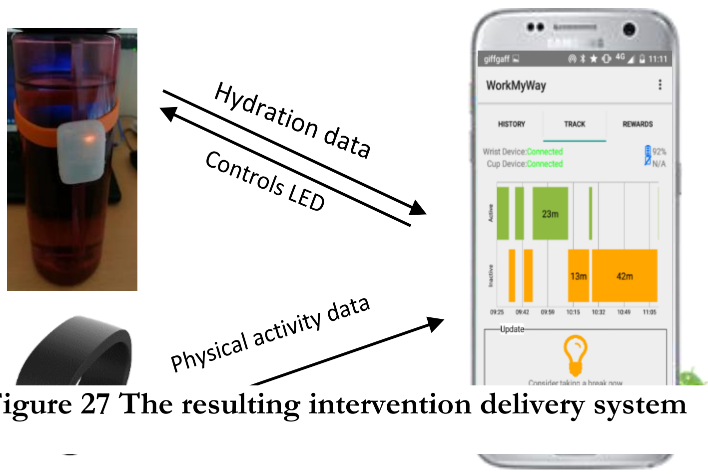

Figure 27 The resulting intervention delivery system

The resulting intervention delivery system (Figure 27), also called *WorkMyWay*, consists of a physical activity monitor (called "wrist device") to be worn by the user, an LED reminder to be attached to a water bottle or any vessel using either a hook or Velcro tape (called "cup device"), and an Android App that communicates with both devices and activates different LED patterns based on real-time analysis of sedentary behaviour data.

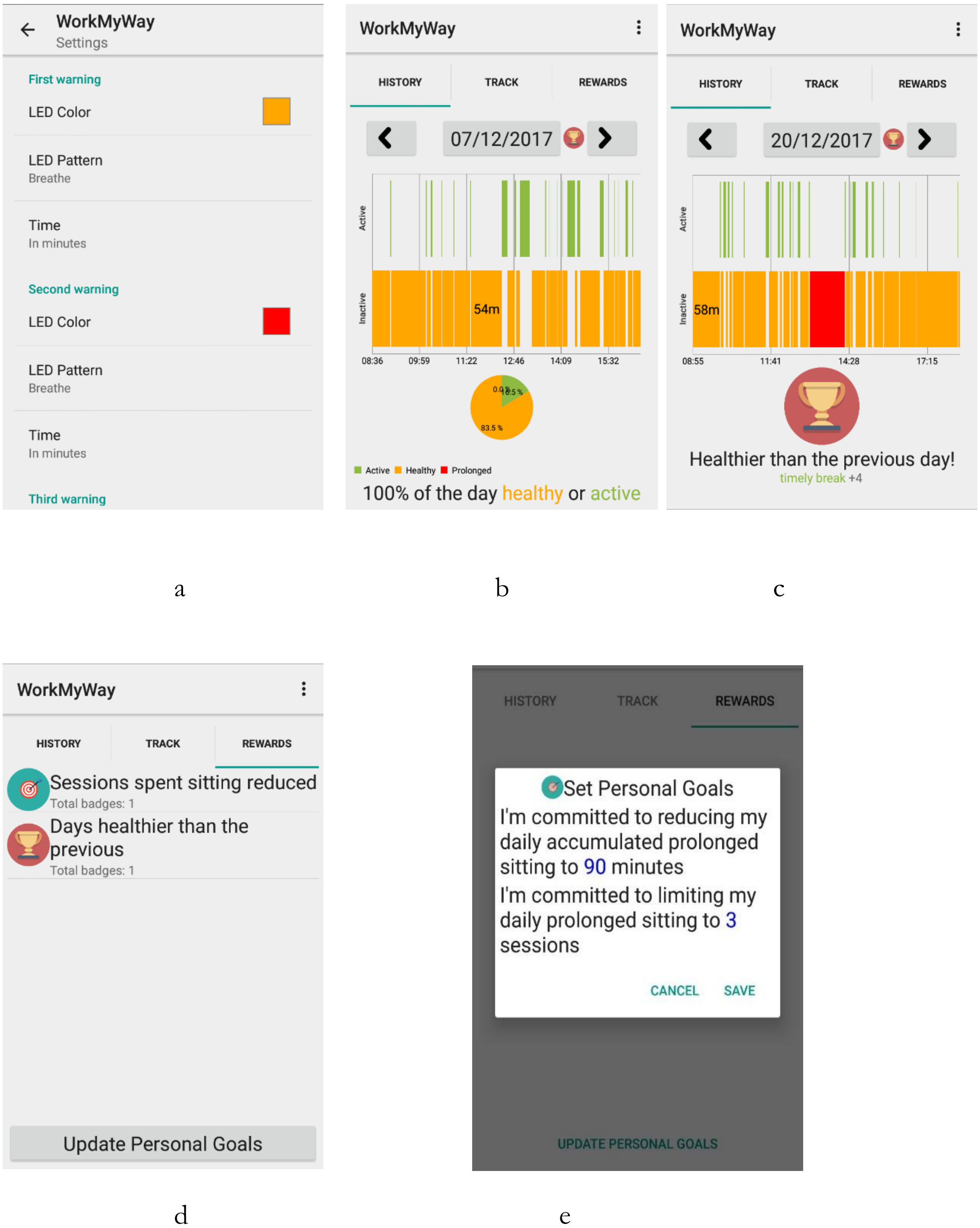

Figure 28 Screenshots of *WorkMyWay* App

The *WorkMyWay* App triggers the LED reminder when the participants' inactive minutes reaches a threshold that can be adjusted by the participant (Figure 28 – a); at the end of each day, the App provides visual and numeric summaries of daily sitting behaviours (Figure 28 – b), as well as affirmative textual feedback if there is improvement from the previous valid tracking day (Figure 28 – c); the App also has a 'reward' section where the user can review their achievements (Figure 28 – d) and set personal goals (Figure 28 – e) to improve their sit-break patterns. The data is synchronised in near real-time between the wrist/cup device and the App via Bluetooth connections. There is also an "about" page (Appendix 14) containing scientific facts about prolonged sitting and breaks and information about the study accessible from the dropdown menu at the top righthand corner.

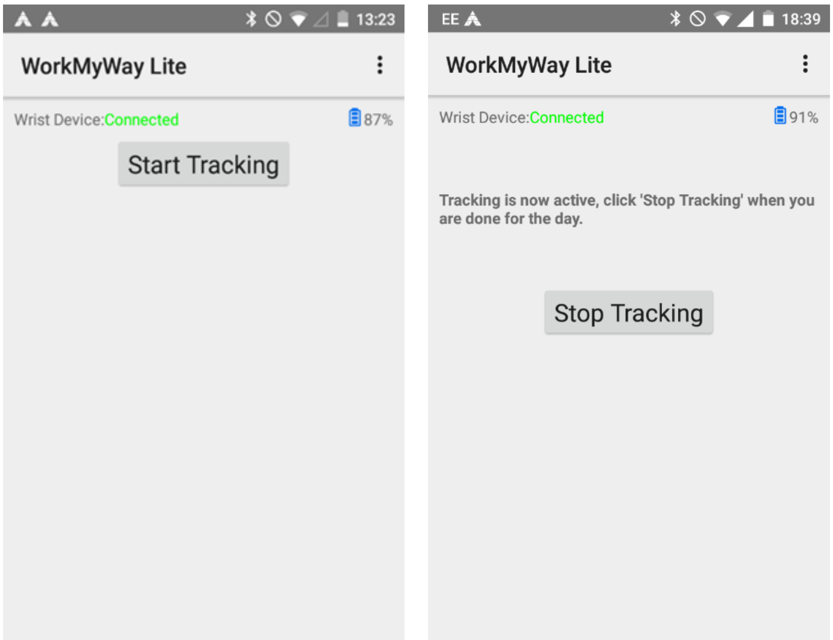

Figure 29 *WorkMyWay* Lite used for baseline assessment

The *WorkMyWay* Lite App, instead, works with the wrist device alone and merely provides the 'tracking' functionality (Figure 29) and was used for baseline measurement.

Protocol for the face-to-face action planning session which are also part of the intervention will be reported in study procedure in the next chapter.

Chapter Six

A feasibility study and process evaluation of WorkMyWay

6.1 Introduction

The development of the *WorkMyWay* intervention has been in accordance with the UK Medical Research Council (MRC) guidance for complex intervention research (Craig et al., 2008), by following through the process of identifying and summarising the best available evidence (Chapter 2), developing a theoretical understanding that is likely to account for the process of change (Chapter 3), and involving the target recipients and stakeholders of the intervention before it was developed (Chapter 3, Chapter 4). The study reported in this chapter is situated within the "feasibility and piloting" phase that comes after the development phase, as per the MRC framework.

Additionally, the MRC guidance on process evaluation of complex intervention is followed (Moore et al., 2014). According to the guidance, although process evaluation can exist at all stages of intervention development and research, when conducted in the feasibility phase, it tends to be more formative and more focused on assessing whether the intervention is implementable, rather than whether it is effective in changing behaviour. Nevertheless, researchers can explore the promise for behaviour change by looking at patterns of change in outcome variables at the participant level and calculating improvements on measures theoretically aligned to the intervention (Orsmond & Cohn, 2015).

For studies involving automated sensors (e.g. physical activity monitor) for outcome measurement and/or intervention delivery, the quality of sensor data has bearings on research and intervention feasibility in the following aspects. Firstly, as demonstrated by Tang et al. (2018), whether data incompleteness resulting from non-wear time was adjusted for in the statistical model significantly altered outcome measures and conclusions about behaviour change. In addition to participants' adherence, technological reliability is arguably another cause for data incompleteness, especially for interventions employing new and unvalidated technologies, such as the *MetaWear* used in *WorkMyWay*. Information about the occurrence and severity of technological failures should be routinely monitored and considered as indicators of feasibility. Thirdly, process evaluation could also explore contexts in which technological failures are more likely to occur, as this will inform the improvement of protocols and development of strategies to minimize the occurrence and adverse impacts of technological failures. Fourth, considering the potential of analysing technology-captured data for understanding the processes of change and identifying active intervention ingredients in larger-scale evaluations (Kumar et al., 2013), it is important to ascertain whether such data sources of satisfactory quality can be collected and used in analysis in the feasibility phase.

In addition to feasibility, acceptability should be another area of focus in process evaluation at this stage (Moore et al., 2014). Indeed, acceptability is integral to feasibility, because interventions disfavoured by participants are unlikely to be implementable in subsequent trials (Michie et al., 2014). This is especially the case for Digital Behaviour Change Interventions(DBCIs), as the quantity and quality of "active ingredient" (e.g. the Behaviour Change Techniques, or the BCTs) received by a user is heavily dependent on the extent to which the user likes and uses the intervention delivery technology (Couper et al., 2010; Glasgow et al., 2011). Hence, it is worth investigating barriers to uptake and adoption of the technology into everyday routine at this stage, so that necessary protocol changes are made and strategies to counter resistance developed before the pilot and formal effectiveness evaluations (Moore et al., 2014).

Several methods have been applied to address different aspects of acceptability in previous studies on DBCIs.

The first and most common approach involves post-intervention interviews to probe into participants' perceived acceptability of DBCIs, subjective experience of participation, likes and dislikes about interventions, and suggestions for improvements (Cooley et al., 2014; Gilson et al., 2008). Some acceptability interviews integrate other functions of process evaluation and explored the process of change and adoption of the intervention into everyday life (Myall et al., 2015). Interview can also assess user experience of the DBCI, which shed light on strategies to increase acceptance and adoption (Muuraiskangas, Harjumaa, Kaipainen, & Ermes, 2016).

However, as a self-report method, interview is susceptible to response biases (Furnham, 1986). Hence, interviews are often complemented by analysis of technology-captured behavioural and usage data. Logs suggesting low usage of a DBCI or certain sections of it can lead to identifications of usability issues, or other barriers to acceptance (Muuraiskangas et al., 2016). DBCIs are advantageous when it comes to monitoring use, because interactions with different intervention components can be recorded separately and automatically. In the literature on DBCIs, usage is variably called dosage, exposure, adherence, and engagement (Couper et al., 2010; Perski et al., 2017), and its measurements are typically derived from digital logs of website access, app launches, frequency and duration of section or module visits, button clicks (e.g. Gouveia, Karapanos, and Hassenzahl 2015; Carr et al. 2013; Couper et al. 2010; Glasgow et al. 2007), and time-stamped sensor readings (e.g. Carr, Walaska, and Marcus 2012; Carr et al. 2015). For interventions where activity tracking and automated tailored feedback plays a central role, adherence to wearing or using the activity monitor is indicative of acceptability of not only the tracking protocol, but also the whole intervention (C. Brakenridge et al., 2018; Cadmus-Bertram, Marcus, Patterson, Parker, & Morey, 2015; Thorndike et al., 2014).

Finally, participants' behavioural and psychological responses to interventions regardless of statistical significance can be reported to testify to acceptability, where possible. For instance, in Matei and colleagues' study, the conclusion about acceptability was supported by positive changes in self-report Sedentary behaviour (SB) and strength of sedentary habit, despite no statistical significance (Matei et al., 2015). For interventions involving prompts for light physical activity breaks in sedentary behaviours, the behavioural responses to prompts at points of decision (e.g. response latency, the proportion of compliance versus noncompliance with prompts) are often reported, as the data reflects the in-situ acceptability of the intervention (Van Dantzig et al., 2013; Wadhwa et al., 2015).

6.2 Aims and objectives

The aim of this study is to evaluate the feasibility and acceptability of the *WorkMyWay* intervention and its technological delivery system in real-life office settings through reporting:

i) the recruitment and retention during the study
ii) usage and quality of tracking during and after the study (i.e. self-directed use)

iii) promise for behaviour change (via reporting psychological outcomes aligned with theoretical underpinnings and patterns of change at individual level)

iv) participants' experience of individual intervention components, including their perceived acceptability, reliability, and underlying mechanisms of impact

v) correlates and barriers of engagement and behavioural responses (exploratory analysis)

6.3 Method

6.3.1 Recruitment and participants

Feasibility studies often do not require formal sample size calculations or power calculation (Thabane et al., 2010). Instead, a target sample size of 15 was set based on i) UX expert's recommendation that testing with 5 users in each round of iteration yields the maximum benefit-cost ratio in terms of uncovering usability and UX issues (Nielsen, 2012); ii) sample sizes used in other studies that evaluated feasibility and acceptability of similar mHealth interventions involving wearable activity trackers, reminder software etc. (Boulard Masson, Martin, Colombino, & Grasso, 2016; Cooley et al., 2014; Mackenzie et al., 2015; Pedersen et al., 2014); iii) the number of study devices (i.e. 9 sets) available to the researcher in the current project for concurrent use; iv) the time remaining in the PhD for ongoing enrolment of new participants into the study. Rolling recruitment was conducted between Sep. 2017 and Jan. 2018.

Any office worker was eligible if s/he was physically abled, his/her work involved significant amounts of desk-based work, s/he normally had the discretion over when to take micro-breaks on workdays. As the study used a rapidly developed system that likely required the researcher to visit participants for troubleshooting from time to time, it was decided to deploy the intervention and technology with a convenience sample at 2 nearby workplaces (i.e. Jubilee Campus and Queen's Medical Centre Campus of the University of Nottingham) for logistical reasons in the feasibility study.

Study information was circulated around staff mailing lists in the School of Computer Science (N= 161, both academics and admin), School of Business (N=30, admin) and School of Education (N=21, admin) (Appendix 15: recruitment material). Posters were put up on notice boards in the above schools, targeting similar groups. In addition, invitations were emailed to 7 participants from Study 2 (Chapter 3) who had opted in to hear about related studies and who were working in the university when the current study started.

25 people responded to the recruitment email and posters by completing the online screening questionnaire. 3 of them were ineligible (1 was a student, the other 2 sign-ups' jobs involved more light physical activity than sedentary behaviour); 1 withdrew before the briefing session because of a lack of line manager's approval for participation; 9 were enrolled on a first-come-first-served basis; the rest 12 were sent emails explaining the reason (i.e. device shortage) for inability to involve them in the feasibility study. Out of the 7 participants from the previous study, 4 responded to the email and participated in the study (P8, P11, P12, P15, referring to the participant ID in the current study, same below) and 1 (P12) of them invited 2 of her officemates (P13, P14) to participate in the study together. This resulted in a total of 15 participants. Their characteristics were summarized in Table 13.

Table 13 Baseline characteristics of feasibility study sample (n=15)

Characteristic	Value
Age in years, mean (SD), range	40.5 (11.0), 25 – 63
Gender, n (%) Male, n (%) Female, n (%)	 3 (20%) 12 (80%)
Highest education level completed, n (%) University preparatory degree, n (%) Undergraduate degree, n (%) Postgraduate degree, n (%)	 2 (13%) 6 (40%) 7 (47%)
Self-reported occupational time spent in sitting (hrs), mean (SD), range standing (hrs), mean (SD), range walking (hrs), mean (SD), range heavy labour (hrs), mean (SD), range Total office hours	 6.2 (1.5), 2.4 – 8.2 0.9 (1.3), 0 – 4.8 0.8 (0.6), 0.145 – 2 0.1 (0.5), 0 – 1.9 8.0 (0.9), 7.25 – 10
Height (cm), mean (SD), range	169.3 (7.5), 155 – 180
Weight (kg), mean (SD), range	72.0 (13.6), 49 – 90
BMI (kg/m^2), mean (SD), range Underweight (=<18.5), n (%) Normal (18.5 – 24.9), n (%) Overweight (25 – 29.9), n (%) Obese (>=30), n (%)	25.0 (4.1), 18.4 – 33.0 1 (7%) 5 (33%) 8 (53%) 1 (7%)
Number of officemates, n (%) 0 1	 5 (33%) 2 (13%)

3 >3	5 (33%) 3 (20%)
School, job role, n (%) Computer Science, admin Education, admin Medicine, admin Computer Science, academics Medicine, academics	 7 (47%) 1 (7%) 3 (20%) 2 (13%) 2 (13%)

At baseline, all of them sat for more than 5 hours on an average workday, except for P4, who used a fixed-height standing desk for most computer-based work (daily standing = 4.8 hrs) and only sat down for meetings and paperwork (daily sitting = 2.4 hrs). P1 and P2 had access to height-adjustable office desks but spent much longer in sitting than standing. As justified in Chapter 2, the behaviour targeted by the intervention is stationary behaviour, because there is also a case for breaking up prolonged standing with regular ambulatory breaks. Hence, those 3 standing desk users were also included in the feasibility study, aiming to elicit feedback from a wider range of potential users.

6.3.2 Study procedure

The study was split into 2 phases because of a limited number of devices. The procedure was identical in 2 phases. Phase I (Oct. 2017 - Jan.2018) and Phase II (Feb 2018 – Apr. 2018) involved 9 (P1-P9) and 6 participants (P10-P15) respectively. Figure 30 provides an overview of study design, which was approved by the School of Computer Science Ethics Committee on 20/9/2017.

During recruitment, potential participants were directed to an online sign-up form hosted on Qualtrics (Appendix 16) to answer some screening questions and provide their contact details and available timeslots. Eligible participants were contacted by the researcher to schedule a briefing session.

The researcher visited each eligible participant's workplace to give a 30-minute briefing session. After giving written informed consent (Appendix 17), the participant completed a pre-study survey on demographics, work fatigue and psychological determinants of occupational sitting and break behaviours (Appendix 18). Then the participant was given an activity tracking wristband and Android smartphone with *WorkMyWay* Lite installed. The researcher gave detailed verbal instructions of how the App and wristband should be used in the following 2 weeks (baseline period) and left each participant with a 1-page 2-

sided "study cheat sheet" (Appendix 19) which included a to-do list, troubleshooting tips and contact details of the researcher.

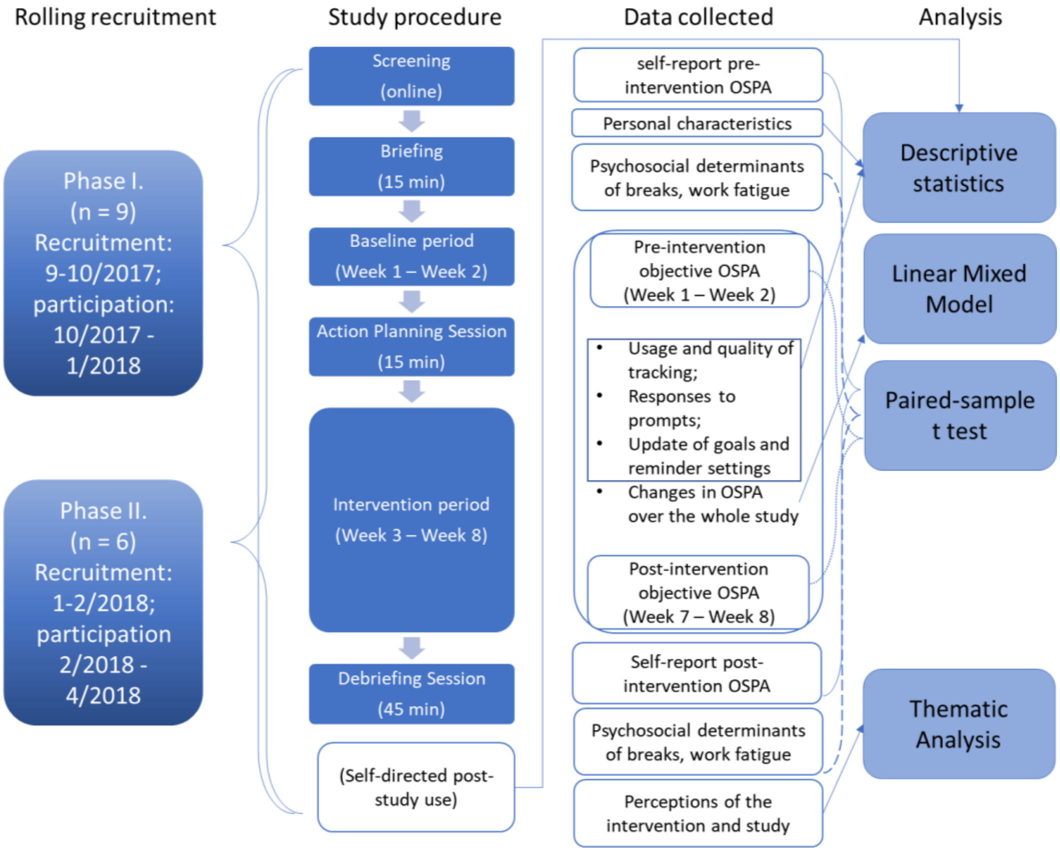

Figure 30 Feasibility study design and timescale

After the 2-week baseline period, the researcher revisited the participant to install the full version of the *WorkMyWay* App on the study phone, fixed a smart LED reminder to vessel (either a bottle or cup) of participant's choice and gave instructions for using the intervention technology. A new "cheat sheet" was provided to each participant (Figure 31). During this session, the researcher also provided the participant with feedback on behaviour data collected during the baseline weeks and conducted an action planning with the participant (see detail in Section 6.3.3 below).

For the following 6 weeks (intervention period), participants used the *WorkMyWay* App together with the wrist and cup devices. To enhance adherence, a weekly reminder email was sent to all participants by the researcher on each Monday morning. If abnormality was observed (e.g. no data uploaded to the server for 3 consecutive workdays, or no data being uploaded for several hours following press of the "*start tracking*" button) in specific participants' data, the researcher would send an individual email to check if the participants needed technical support. The researcher was available throughout the study period in case any participant needed help.

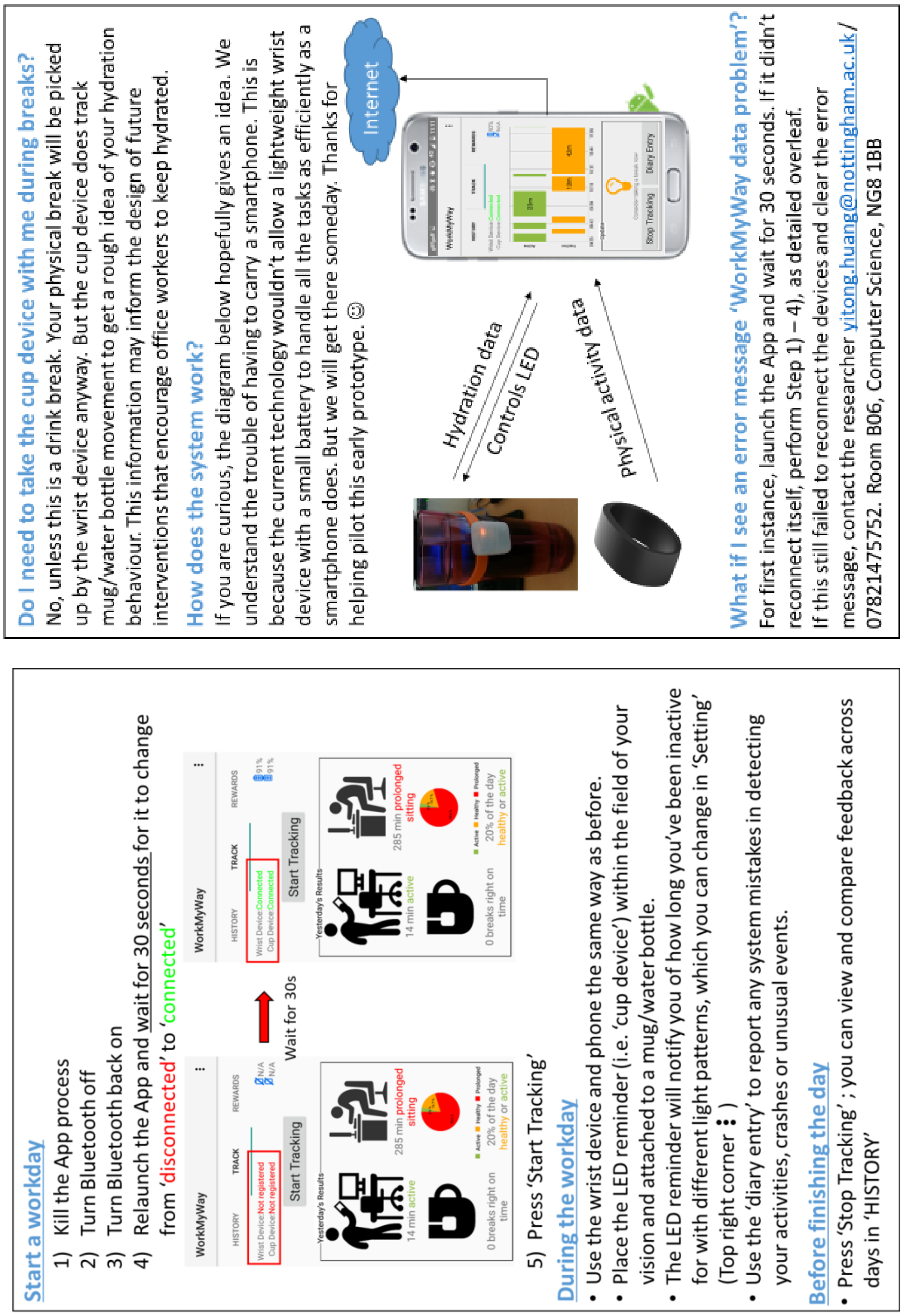

Figure 31 Participant "cheat sheet" for the intervention period

In the 3rd week of the intervention period, the researcher followed up with another email that asked participants to review the "history" section in the App and compare their performance against the original goals they set for themselves 2 weeks ago, along with instructions to adjust the goal and reminder setting in the App if the participant felt the need.

If any atypical out-of-office days were expected during the study and reported by the participant, those were marked as "holiday" for analytic purposes and excluded from analysis, in which case participants could use the device for extra workdays to make up for "holidays" to complete a full 30-workday intervention regime. These "holidays" included weekends, public holidays, non-workdays based on individual work contracts (e.g. Friday for those working only Monday to Thursday), planned annual leaves, fieldwork, conference and training days, but not days with meetings if they were typical in the participant's day-to-day work.

Within 1 week after the 6-week intervention period, each participant attended a 45-min debriefing session, which involved a self-administered post-intervention survey and a process evaluation interview (see detail in section 6.3.5 and Appendix 22). Participants were offered the choice to keep and continue using the devices after the study for as long as they wanted, unless the devices were broken or needed for the next phase in the study or for other research studies. If participants opted in to post-study use, they were reassured that their data after the study period would be analysed to see the level of usage but not physical activity; the researcher would only contact the participant to collect the devices if no data was uploaded from the participant for 2 months.

6.3.3 Motivational interview and action planning protocol

The action planning session after the 2-week baseline period followed a protocol (Appendix 20) adapted from the Brief Action Planning (BAP), which is a support technique used in clinical practices to facilitate patients in forming action plans that they feel confident to achieve (Gutnick, Reims, Davis, & Gainforth, 2014).

The behaviour change technique (BCT) of action planning has been detailed in Chapter 2 and Chapter 5. In brief, forming action plans or implementation intentions is Type 2 strategy that produces consequences on Type 1 system, as it connects a goal-directed behaviour with an anticipated situation and hence pass the control of the behaviour over to the environment (Gollwitzer, 1999). In addition to action planning, the BAP protocol (Gutnick et al., 2014) is grounded in the principles and practices of Motivational Interview (MI), which emphasises collaborations between the clinician and the patient (in this case, the researcher and participant/user) rather than a prescription for change, and acknowledges individual's expertise about their own lives (Miller & Rollnick, 2002). In MIs, the clinician guides the patient to consider a specific behaviour change target and gradually elicit and strengthen the patient's own intention for change. The application of MI has been found to outperform traditional advice giving in a broad range of behaviour change contexts (Rubak et al., 2005). The current study adapted the 3 questions[4] and 5 response skills[5] from the BAP (Gutnick et al., 2014) while incorporating technological features form the *WorkMyWay* system and vignette of the baseline data (Appendix 21) into the protocol to deliver the BCTs of goal setting, feedback on behaviour, review behaviour goals, commitment, action planning, prompts and cues, conserve mental resources and habit formation. For instance, instead of prescribing a desired end state for the participant, the researcher could ask, *"now that we've looked at your data and talked about prolonged sitting and health, is there anything you would like to do for your own health in the workplace in the next week or two?"* If the participant was unsure, the researcher then needed to ask for the participant's permission to share some graphs illustrating potential end states that s/he could consider pursuing. Then the participant was guided to make more specific action plans in terms of how often they would to break up sitting depending on the type of working task at hand and to make use of the 3 configurable LED events to support execution of the action plans.

6.3.4 Measures

6.3.4.1 Personal characteristics

Key participant characteristics, as measured with questionnaires at baseline (the screening and 1st briefing), included age, gender, highest level of education completed, job

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[4] 3 questions:
"Is there anything you would like to do for your health in the workplace in the next week or two?"
"On a scale of 0 to 10, how motivated are you to complete the plan?"
"Would you like to set a specific time to check about your plan to see how things are going?"

[5] 5 response skills: offer a behavioural menu (of goals), SMART (specific, measurable, achievable, relevant and time-bound) planning, elicit a commitment statement, collaborative problem solving for low confidence, and follow-up.

description, whether they used a sit-stand desk in the office, number of office mates, and Body Max Index (BMI; calculated based on self-report height and weight).

6.3.4.2 Usage, dosage and adherence

In this study, the term "usage" broadly refers to participants' use of different technological features (e.g. "history", "reward", "goal setting" sections); "dosage" refers to the quantity of prompts delivered with the LED reminders; "adherence" refers to participants' use of the "tracking" function (i.e. adherence to the monitoring protocol).

The researcher initially planned to objectively quantify usage of all major functions within the *WorkMyWay* App by calculating the time elapsed between 2 button presses (e.g. press on the "history" tab indicates the start of a "feedback" session, press on other tabs indicates the end of the session). However, the recording of "feedback" session time was found infeasible in practice, because sometimes the switches between the "history" tab and other tabs happened so swiftly and frequently that the recording and uploading of the interactional data could interfere with that of the *MetaWear* sensor data. To compromise, only interactions with less frequently used buttons such as "start tracking" and "stop tracking", and changes to the reminder interval and goal settings were monitored for usage. Wherever the word "day" is used in the study, it refers to "workday".

The following measures were operationalised:

1. **Usage of tracking:** the number of days on which the participant used the tracking function. Those days were called "tracking day".
2. **Use of the "goal setting" section:** the number of days on which the goal was updated.
3. **Use of the "action planning" section:** the number of days on which the reminder setting was updated.

All the above measures should have 30 (intervention days) as the largest and 0 (intervention day) as the smallest possible value.

6.3.4.3 Quality of tracking

As the *MetaWear* platform used in the study was relatively new to the market and unstable, there were periods when physical activity data was lost due to accelerometer crash, or failures to restore Bluetooth connection and retrieve data from the wearable sensor after some incidences of disconnection. Based on the classification rule described in Chapter 5, whenever the tracking was on, a period with 0 count for 40 or more consecutive epochs (i.e. no data for 10 minutes) would be classified as **"invalid tracking"**. Other epochs were all valid and classified as either active or inactive based on the decision rules detailed in Chapter 5. Tracking days with less than 3 hours of invalid tracking AND more than 3 hours of valid tracking were considered as "**valid (tracking) days**"; the remaining tracking days were classified as **"invalid days"**. **Quality of tracking** was operationalised as the percentage of tracking days that were valid.

Notable, **quality of tracking** is determined by the reliability of the tracking technology and independent of the participants' subjective motivation to contribute high quality data, unlike "density of (valid) use" used by other researchers (Meyer, Wasmann, Heuten, El Ali, & Boll, 2017) which was an indicator of data completeness determined by a combination of participants' adherence and the reliability of the tracking devices (Tang et al., 2018). Just for comparison purposes, the author also calculated **density of valid use**, as the percentage of valid tracking days out of the possible 30 days.

6.3.4.4 Response latency and compliance with prompts

As the system was designed to keep the LED reminder on until a break was detected, it sometimes logged multiple timestamps in a row for a single prompting event. Hence the author decided to combine prompts with an interval of less than 30 minutes as a single "prompting event", and use the timestamp of the first delivery as the timestamp of the event. For analytic purpose, the onset of the next break following the prompt event was regarded as a response to that prompt, and the time elapsed in between as "**response latency**", although the user could have taken the break without an intention to respond to that prompt. **Compliance** was defined as the percentage of prompts responded to with a latency of 15 minutes or less.

6.3.4.5 Occupational sitting and physical activity (OSPA)

As detailed in Chapter 2 and Chapter 5, the inactivity captured and visualised in the system should be more precisely called "stationary behaviour" (i.e. "any waking behaviour done while lying, reclining, sitting, or standing, with no ambulation, irrespective of energy expenditure") (Tremblay et al., 2017). Hence, the main behavioural outcome measures included total **stationary time per day**, **the number and duration of prolonged stationary bouts** (i.e. periods of uninterrupted stationary time that was 60 min or above), and **ambulatory time**.

Self-reported daily sitting/standing/walking/heavy labour at work was measured both pre-study during the screening stage and post-study at the debriefing session, using Occupational Sitting and Physical Activity Questionnaire (OSPAQ) (Chau, Van Der Ploeg, Dunn, Kurko, & Bauman, 2012), which has demonstrated satisfactory validity and responsiveness previously and been widely applied in assessing office workers' activity level at work (e.g. Fountaine, Piacentini, & Liguori, 2014; Jancey, Tye, McGann, Blackford, & Lee, 2014; van Nassau, Chau, Lakerveld, Bauman, & van der Ploeg, 2015). For comparison with objective measures, self-reported stationary time was calculated by adding up sitting and standing time, and ambulatory time by adding up walking and heavy labour time.

6.3.4.6 Work fatigue

Based on research on personal resources and ego-depletion (Baumeister, Bratslavsky, Muraven, & Tice, 1998), (Trougakos & Hideg, 2009) proposed that within-work breaks could help manage energetic resources on workdays. Hence, in this study, the researcher set to measure the construct of "work fatigue", as a potential psychological consequence of altering break behaviours.

Several survey instruments exist to measure different dimensions of work-related fatigue (e.g. Swedish Occupational Fatigue Inventory (SOFI)(Åhsberg, Gamberale, & Kjellberg, 1997); the Occupational Fatigue Exhaustion Recovery (OFER) scale; the Chronic Fatigue Scale of the Standard Shiftwork Index (SSI-CFS)). There is no agreed-upon gold standard definition of occupational fatigue and evidence for the validity and reliability of those instruments is limited (Patterson et al., 2018). Frone and Tidwell (Frone & Tidwell, 2015) reviewed prior measures of work fatigue-related constructs and proposed the definition of work fatigue as "extreme tiredness and reduced functional capacity that is experienced during and at the end of the workday". Consequently, they developed the 3-Dimensional Work Fatigue Inventory (3D-WFI), and demonstrated its psychometric quality and construct validity (Frone & Tidwell, 2015). As the 3D-WFI measures all 3 dimensions (**physical, mental and cognitive**) of **work fatigue** that could be relevant to micro-breaks, it was adopted as the basis for deriving the work fatigue measure in the current study. The following adaptation was made - the original wording of "12 months" was changed to "past month" and response labels changed accordingly to "4-Everyday, 3-More often than not, 2-about half the time, 1-occasionally, 0-never", because the current study took survey measurement at 2 timepoints only 8 weeks apart.

6.3.4.7 Psychological determinants of breaks

The behavioural diagnosis in Chapter 4 identified theoretical constructs relevant and prominent in influencing office work breaks behaviours, which lead to selection of BCTs that target those constructs. A questionnaire (Appendix 18) was specially designed to assess psychological outcomes aligned with the targeted theoretical constructs (e.g. perceived behavioural control, memory, habit for regular work breaks). Some of the wordings in a previous questionnaire on psychosocial factors of occupational sitting (De Cocker et al., 2014) was adopted. The 4-item automaticity subscale (Gardner et al., 2012) of the Self-Report Habit Index (SRHI) (Verplanken & Orbell, 2003), were adapted to assess regular micro-break habit.

6.3.4.8 Water break duration

Assuming the user attached the LED device to vessels as instructed, walk movements detected on the LED device (slightly milder than wrist-movement and hence with a lower threshold) could be considered a proxy measure of "water break" for analytic purposes. The start or end of an event was determined based on a similar "double-threshold" principle used for the human break detection detailed in Chapter 5 (Figure 26) with an A of 0 and B of 20. Daily water break duration was the sum of durations of those bounded "LED walking movement" events.

6.3.5 Process evaluation interview

A semi-structured interview was conducted by the author with each individual participant after the intervention period. The duration of these interviews ranged from 17 minutes to 36 minutes (mean = 25 minutes). An interview guide and schedule (Appendix 22) was constructed based on the MRC guidance and covered the following topics: acceptability of the study and intervention process, most and least useful technological features (e.g. tracking, prompting, real-time visualisation, history, reward), recalled use of each component, perceived behaviour change and processes of change (i.e. mechanisms of impacts), facilitators and barriers of using *WorkMyWay* and improving break behaviours.

One-to-one interviews were chosen over group interviews, to provide each respondent with an opportunity to share individual experiences in greater depth without being conscious of how they might come across to their colleagues or managers. The scheduled 30-min timeframe also allowed sufficient time to go through data feedback on several interesting days in the 'history' section in the App. The interviews were audio recorded with participants' consent. All interviews were transcribed verbatim and anonymised.

6.3.6 Quantitative Analyses

Accelerometer data were pre-processed with the classification algorithm implemented in a Python script (Python Software Foundation, 2014) to extract the outcome measures, which were than imported to SPSS for Windows version 22.0 (IBM Company, Chicago, IL, USA) for statistical analysis. Usage and adherence measures was summarised descriptively. Differences between pre-intervention (Week 1 – Week 2) and post-intervention (Week 7 – Week 8) periods in accelerometer-captured and self-reported OSPA, work fatigue and psychosocial determinants of prolonged sitting and break behaviours were assessed using paired-samples t-tests. Statistical significance was set at .05.

As participants were free to pause using *WorkMyWay* for any period during the study for any reason (e.g. out-of-office, atypical workday, tech problem etc.), it was common for a subject to have missing data for one or more days. As a repeated measures ANOVA would require removing the either the whole column or the subject if a subject has missing data for a single time point (West, Welch, Ga, & Crc, 2007), it was deemed unsuitable for analysing the change process in this study.

Instead, Linear Mixed Model was used to i.) avoid list-wise deletion because of missing data points, ii.) account for correlations between measurements within each subject, and iii.) model individual differences with random intercepts and slopes. The number of days since intervention commencement ('time') was treated as a covariate, although it could have been treated as a categorical variable and coded with a set of 9 orthogonal polynomial codes. However, in this study, the researcher was not interested in effects of day beyond the linear effect, asking simply whether the outcome variables increased over the course of the 30-workday intervention period. To identify the best fit model, Maximum

Likelihood was used as the estimation method, and Akaike Information Criterion (AIC) and Schwarz's Bayesian Criterion (BIC), and Log likelihood tests were used.

Bivariate correlational analyses were conducted to explore potential relationships between all the above measures and Pearson's Correlation Coefficients with a significance of .05 or less were reported.

6.3.7 Qualitative analysis and triangulation

The researcher transcribed audio recordings of interviews, which enabled familiarisation with the data. Data were then analysed for themes related to acceptability of the *WorkMyWay* intervention and study using a thematic analysis approach (Braun & Clarke, 2006). Thematic analysis involved familiarisation with the data, generating initial codes, searching for themes, reviewing potential themes, defining and naming themes in a code book, final analysis and write-up. Codes were meaningful labels to group and organise data and could be about a certain aspect of the technology (e.g. the history function) or experienced change in oneself and the surrounding environment (e.g. more awareness of sitting). The software package NVivo version 12 (Qualitative Solutions and Research International) was used to facilitate the organisation of codes and themes. In addition, a one-page summary is created for each participant, summarising his/her profile, experience of the study, views of and responses to the intervention etc.

6.4 Results

6.4.1 Usage and quality of tracking

The 8-week study period collected 472 days of usage data (baseline = 97 days; intervention = 375 days), out of which 337 were valid tracking days (baseline = 75 days; intervention = 262 days). On those valid days, daily valid tracking time ranged from 182.75 minutes to 632.25 minutes, with a mean (SD) of 414.2 (94.6) minutes, or 6.9 (1.6 hours); daily invalid tracking time ranged from 0 minutes to 179.5 minutes, with a mean (SD) of 23.35 (37.6) minutes and a median of 0 minutes. Invalid tracking was mostly caused by Bluetooth disconnection and data loss (to be detailed in qualitative results).

Figure 32 provides an overview of the data points on usage and quality of tracking since the installation of *WorkMyWay* full version. Week 1 and 2, in which the Lite version was used for baseline assessment, were excluded from the graph. Based on an initial visual inspection of the graph, P4, P6, P7 and P10 were particularly compliant with the protocol (many days of tracking recorded) and presumably experienced few data problems (few invalid days). P1, P2, P3, P5, P8, and P9, who all participated in Phase I, seemed to be really struggling with the technology, which induced days of disuse; after the researcher helped reset the connection, they could reuse the technology for several days before it was broken again. P11 was the most uncompliant participant whose usage was patchy. P12, P13 and P14, who shared an office, had similar compliance but varied quality of tracking due to different levels of competence in using technology; P12 and P14 helped P13 with troubleshooting the technology and hence carrying on with the study. P15 also experienced some technological problems but was able to fix the problem and restore connection by himself with the researcher's instruction over email.

(See also Appendix 23 for each participant's usage and experience)

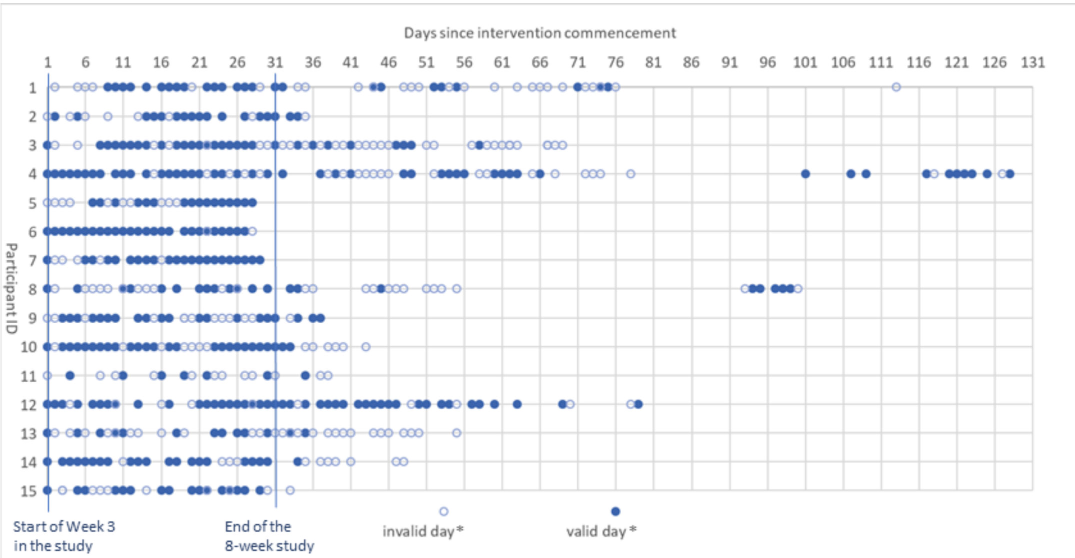


Figure 32 Usage pattern of the tracking function in *WorkMyWay* full
*Tracking days with less than 3 hours of invalid tracking AND more than 3 hours of valid tracking are considered "valid days"; the remaining tracking days are "invalid days".

6.4.1.1 Intervention period (Week 3 – Week 8)

All participants completed the 6-week intervention protocol (i.e. 100% retention). Over the intervention period, the tracking function was used for 15 to 30 workdays out of a possible 30 workdays, with a mean (SD) of 25(4) days of use and a median (25^{th}, 75^{th} percentile) of 26 (23, 28) days. This yielded a mean adherence rate (SD) of 83.3% (14.0%) and a median (25^{th}, 75^{th} percentile) of 86.7% (76.7%, 93.3%).

The number of valid days (i.e. days with >3 hours valid tracking time and <3 hours invalid time) tracked over the intervention period ranged from 6 to 26 days across participants, with a mean (SD) of 17.5(5.3) valid tracking days and a median (25^{th}, 75^{th} percentile) of 16 (14.5, 21.5) days. The mean (SD) quality of data (i.e. the percentage of tracking days that were valid) was 68.6% (14.9%), with a median (25^{th}, 75^{th} percentile) of 71.4% (59.3%,81.1%). The density of valid use (i.e. indicative of overall data completeness) averaged at 58.2% (SD = 17.8%), with a median (25^{th}, 75^{th} percentile) of 53.3% (48.3%,71.7%).

6.4.1.2 Post-study period

After the 8-week study was completed, 11 (73%) participants expressed an intention to continue using the devices in their own interests, but 2 of them in Phase I (P6 and P9) had to stop earlier than they would like to because the devices need to be collected for repair and used for Phase II data collection. The main reasons for not opting in (P2, P5, P7 and P15) to continued use included (i). leaving the university for a new job (n=1), (ii). having technical difficulties setting up (n=2), (iii). discomfort to wear the wristband (n=2). The researcher also found the easily broken casing of the LED reminder potentially a barrier to long-term adoption.

Among the remaining 9 participants (P1, P3, P4, P8, P10-P14) who could use the devices freely for as long as they wanted, the last of day of use (number of days since study end) ranged from 8 (P11) to 98 (P4), with a median of 39 and a mean (SD) of 44.8 (32.5). As expected, adherence to tracking (M=55.8%, SD=19.3%) and quality of tracking (M=35.7%, SD=5.4%) during self-guided post-study use were significantly lower than within-study adherence (M=81.5%, SD=15.3%) and quality (M=67.3%, SD=5.4%), confirmed by paired-samples t-tests ($t(8)=3.619$, $p=.007$ for adherence; $t(8)=4.3$, $p= 0.003$ for quality). To sum up, self-directed use after the 8-week study generated a further 211 days of usage data, out of which 91 days were valid.

6.4.2 Overall behavioural and psychological responses to the intervention

As Table 14 indicates, there was a trend of increase in self-reported walking, sitting and standing time, although the difference was small in the latter 2 measures. The direction of change of objectively measured stationary time was consistent with that of self-report (i.e.

increasing); however, objectively measured ambulatory time seemed to decrease, in contrast to self-report. None of the changes were statistically significant.

It is worth noting that self-reported stationary time was significantly higher than that based on wearable tracking data based on paired-samples t-tests (t=5.058, p<.001). This was probably because data loss problems caused underestimation in the latter measure. In addition, participants' objective and self-reported behavioural measures (e.g. stationary time, ambulatory time, total tracking/total work time) were not correlated with each other, suggesting the extent of data incompleteness varied across participants.

Table 14 Behavioural and psychological measures at baseline and post-intervention (n=15)

*Stationary time: measured as the sum of sitting and standing time in OSPAQ and as 'inactive' time based on the classification algorithm defined in *WorkMyWay*

#Ambulatory time: measured as the sum of walking and heavy labour in OSPAQ, and as 'active' time based on the classification algorithm defined in *WorkMyWay*

(-): strength of factors negatively contributing to regular break behaviours

	Pre-intervention, mean (SD)	Post-intervention, mean (SD)	Trend (mean difference)	*t (p)* value
Tracking data (based on valid days)				
Valid tracking time, min/workday	430.4 (45.2)	419.7 (51.4)	-10.7	-.627 (.541)
Invalid tracking time, min/workday	15.7 (16.3)	27.3(31.7)	11.7	1.768 (.099)
Stationary*, min/workday	355.0 (57.3)	356.7 (56.3)	1.7	.115 (.91)
Ambulatory#, min/workday	75.4 (45.9)	63.0 (28.7)	-12.4	-1.288 (.219)
Duration of prolonged stationary bouts, min/workday	176.1 (78.7)	188.3 (95.3)	12.1	.591 (.564)
Number of prolonged stationary bouts, n/workday	1.8 (.8)	1.8 (.7)	-.05	-.252 (.804)
OSPAQ				
Work time, min/day	482.5 (55.7)	492.5 (77.5)	10.1	.569 (.579)
Siting, min/day	369.0 (91.1)	373.3 (78.8)	4.3	.209 (.838)
Standing, min/day	56.0 (77.9)	58.6 (61.2)	2.6	.138(.892)

Walking, min/day	49.5 (38.7)	60.3 (50.6)	10.8	1.131 (.277)
Heavy labour, min/day	7.9 (29.4)	.29 (1.1)	-7.6	-.998 (.335)
Stationary*, min/day	425.0 (60.9)	431.9 (46.3)	6.9	.379 (.710)
Ambulatory#, min/day	57.4 (58.2)	60.6 (50.4)	3.2	.289 (.777)
Determinants of breaks				
Break intention	6.07 (.89)	6.20 (.86)	.13	.695 (.499)
Positive outcome expectancy	6.18 (.75)	6.27 (.63)	.08	.673 (.512)
Perceived behavioural control	6.20 (.78)	6.33 (.82)	.13	.487 (.634)
Perceived barrier: heavy workload (-)	5.07 (1.9)	5.00 (1.91)	-.07	-.163 (.872)
Perceived barrier: discouraging organisational culture (-)	1.80 (.561)	1.80 (.941)	.00	.000 (1.000)
Perceived facilitator: organisational culture encouraging breaks	6.00(1.00)	6.07(.80)	.07	.202 (.843)
Regular micro-break habit (automaticity subscale)	4.41 (.71)	4.85(.44)	.43	2.606 (.021*)
Retrospective memory of breaks	3.47 (1.47)	6.30 (.80)	2.83	7.926 (<.001***)
Need for prospective memory aid (-)	5.70 (1.07)	4.93 (.92)	-.77	-2.661 (.019*)
Outcomes of breaks: work fatigue				
Physical fatigue	2.14 (.64)	2.05 (.60)	-.08	-.807(.433)
Mental fatigue	2.69 (.96)	2.61 (.86)	-.07	-.504 (.622)
Cognitive fatigue	1.57 (.54)	1.78 (.52)	.21	1.809 (.092)

There were no clear patterns of change in measures of psychosocial determinants of breaks, except for those on habit, retrospective memory, need for prospective memory aids. Specifically, the strength of habit of taking regular work breaks, as measured by the 4-item automaticity subscale *("taking regular micro-breaks throughout workdays is something…1. I do automatically 2. I start doing before I realize I am doing it 3. I do without thinking 4. I do without having to consciously remember")*, was significantly improved post-intervention. The retrospective memory of daily sitting and break taking measured with 2 items *("At the end of each day, I have an idea of how much time I've spent in prolonged sitting in total"; "at the end of each* *day, I have an idea of how often I have taken breaks")* was also significantly improved post-intervention. Finally, the need for prospective memory aids for taking breaks measured with 2 items (*"I find it difficult to keep track of time when engrossed in work"; "To take regular breaks, I need better prompts/cues to remind me to stand up when I've been sat for too long")* was significantly reduced.

6.4.3 Behavioural change over the study

Linear mixed model was built with time as the covariate, percentages of daily time spent on prolonged stationary bouts as the dependent variable, and participant ID as the grouping variable. The model with a random slope, random intercept and fixed intercept was identified as the best fit model following a backward elimination procedure, suggesting significant differences between subjects in both trends of behavior change and behaviour at onset. The fixed intercept coefficient was .451 (t=11.256, p<.001), which meant at onset of intervention, participants on average had 45.1% of their days spent on prolonged stationary bouts (>60 minutes), though there were significant inter-subject difference. The fixed coefficient for time was not significant and hence removed from the model, which suggested no overall linear growth or decline in daily time spent on prolonged stationary bouts was observed for the sample as a whole. Visual inspection of the regression lines in scatterplot (Figure 33) found trends of decrease (i.e. improvement in the target behaviour) in 8 participants (P5, P6, P7, P9, P10, P11, P12, P13) and increase in 5 participants (P2, P3, P4, P14, P15). A summary of each participant's profile and trajectory over the study period, such as changes in other behavioural measures, perceived changes and mechanisms of changes are detailed in Appendix 23. Simple linear regressions performed on each participant's data separately found the slope indicating change was only significant for 3 participants (P2 (increase, P6 (decrease) and P7 (decrease)), detailed as follow (*t, p* value pertain to significance of the time slope and R^2 refers to the variance explained by the simple regression model):

- P2: Y = .035X (t=12.636, df=13, p<.000, R^2=92.5%)
- P6: Y=.687-.012X (t=-2.718, df=24, p=.012, R^2=23.5%)
- P7: Y=.505-.013X (t=-2.671, df=20, p=.015, R^2=26.3%)

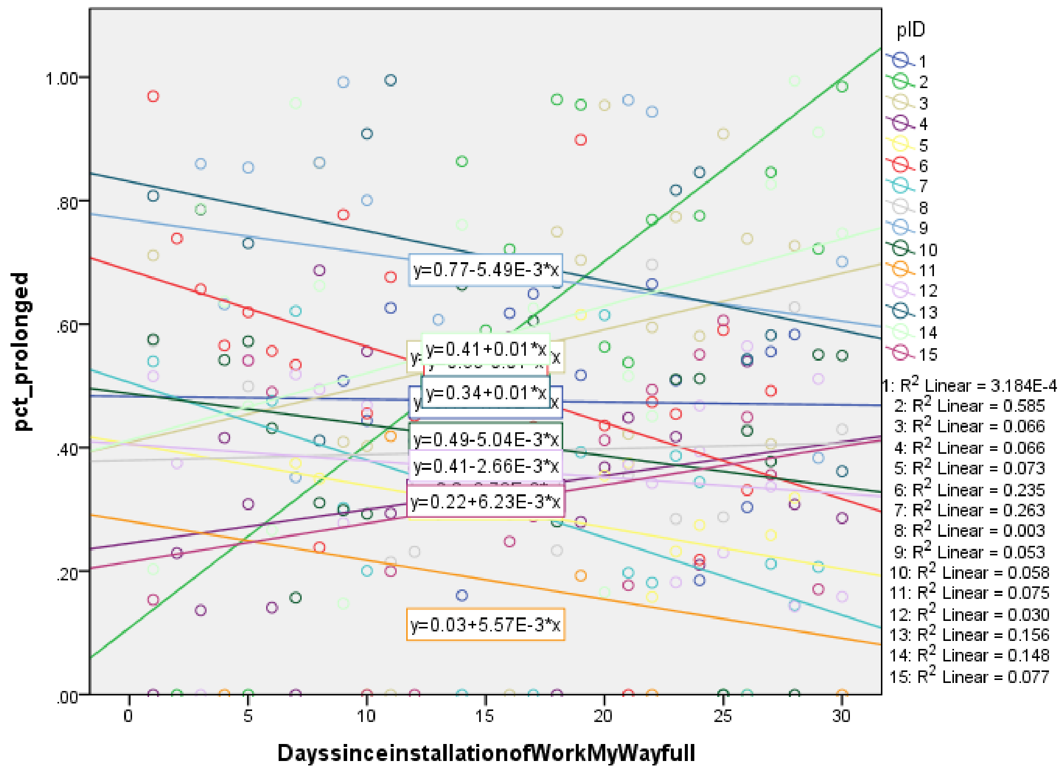


Figure 33 Changes in percentage of daily time spent on prolonged sitting over the study period by participant ID (pID)

6.4.4 Subgroup differences between Phase I and Phase II

No statistically significant difference was found between phase I and phase II participants in measures of adherence, quality, compliance, mean response latency, dosage of prompts or the usage of the different functions, except that phase I participants (n=9, M = 3.67 days, SD = 2.236) updated the reminder setting on more days during the study than Phase II participants (n=6, M = 1.33 days, SD = .516) (t= 2.483, p = .027). There was no significant difference in the change in behavioural or psychological measures between participants from 2 phases except for stationary time captured by the technology, as Phase I participants increased (M=27.2 min/day, SD=38.2) while Phase II participants decreased (M = -36.5 min/day, SD=63.8), (t=2.435, p=.03). This as the technology reliability is improved, there will be a stronger case for the intervention to produce positive behaviour change outcomes in terms of SB reduction.

No statistically significant difference was found between participants who opted into post-study use and those who did not, in the adherence and efficiency measures, dosage of prompts or latency in responses to prompts, or the usage of the different functions.

6.4.5 Results from exploratory analysis

This section briefly presents results from analyses that were exploratory in nature and that could be informative for future research, though they would not be discussed in depth in this thesis because of word limit.

6.4.5.1 Responses to prompts

A total of 698 timestamped prompting events were recorded. The total number of prompts received by each participant over the study period ranged from 13 (P11) to 116(P3), with a median of 37. The mean average prompts received per participant tracking day was 1.8 (SD=1.1).

As Figure 34 shows, slightly over a third of the prompts (269 (38.5%)) were responded to within 15 minutes. Within this category, the majority were responded within 5 minutes (113 (16.2%), followed by 5-10 min (85 (12.2%)) and 10-15 min (71 (10.2%). For those data points with >2 hours response latency (71 (10.2%), it was very likely that a period of disconnection occurred after the prompt delivery which caused the system to lose the record of the actual response. Future research, after fixing the connection issue as well as possible, may investigate how periods of inevitable data loss should be handled in real-time feedback and retrospective analysis.

Figure 35 show how latencies of responses differed across participants. Due to the small sample size, short study period and frequent data problems, it was meaningless to collate this process data with the outcome measures, which, however, could be done in larger trials in the future.

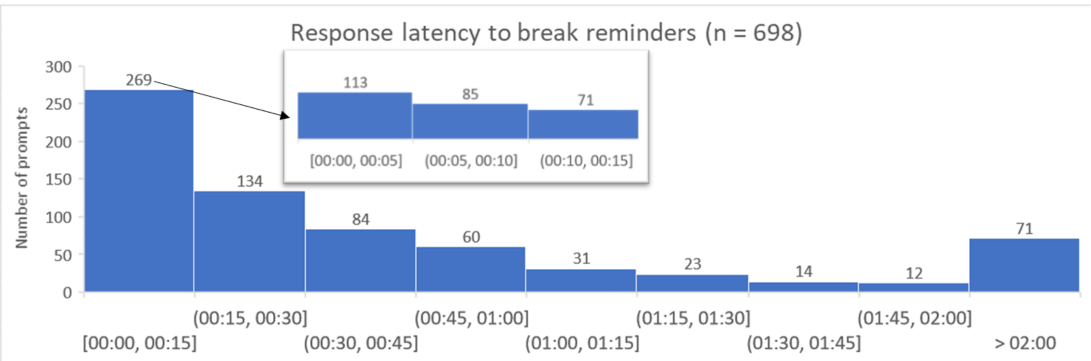


Figure 34 Latency of responses to LED reminders

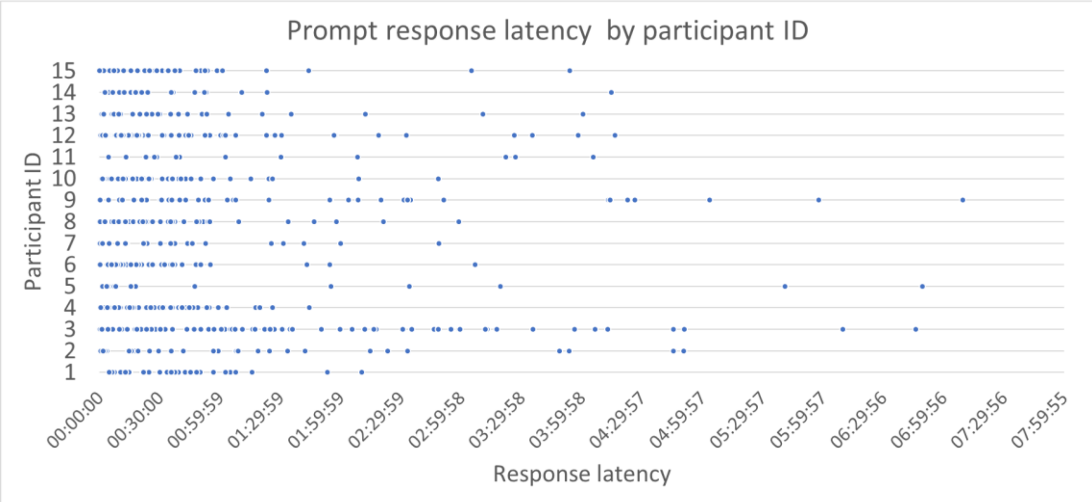


Figure 35 Latency of responses by participant ID

6.4.5.2 The association between the LED device use and behavioural outcomes

For days on which prompts delivery was recorded (n=176 days), mean response latency to break prompts was positively correlated with total prolonged sedentary time (r=.431, p<.001), and duration of longest sitting bout on the day (r=.686, p<.001). This meant that days on which prompts were responded to more quickly tended to have less prolonged sedentary time.

For days on which usage of the LED device was recorded (n=168), "water break duration" (operationalised as the "duration of events where the user walked with the LED device") positively correlated with the user's ambulatory time captured by the wrist device (r=.257, p=.001). Multiple linear regression further confirmed that daily water break duration positively predicted daily ambulatory time (B=.272, p=.002) even after adjusting for daily valid tracking time (B=.111, p<.000) which could be considered a covariate affecting both recorded LED movement and daily ambulatory time. This suggested on days with equal amount of valid tracking time, more water breaks, or at least more manipulations of the LED device seemed to be predictive of more ambulatory time of the user.

6.4.5.3 Individual characteristics associated with usage and quality of tracking

Several significant bivariate correlations were found. Perceived workload (assessed with item Q25 *"Heavy workload and tight deadlines impel me to sit and work continuously longer than I would like to"*) at baselined was negatively correlated with compliance (r=.-619, p=.014), which was understandable and suggested those reporting more workload and time pressure on break behaviours were less likely to take breaks in response to prompts.

There was a positive correlation between self-reported walking and perceived health outcomes of taking regular work breaks, both of which were negatively correlated with quality of tracking and adherence. This could be because those who were more aware of the issue and who were already active at work at baseline were in less need for an intervention, and hence less engaged with the technology; or it could be because it was more difficult to track active workers, as they moved between locations more often than their less active counterparts.

6.4.5.4 Experiential factors associated with behavioural outcomes

There was significant correlation between individual's mean latency in responding to break prompts and quality of tracking (n=15, r=-.536, p=.040), which suggested the less frequently a participant experienced technology failures and data loss, the faster s/he took a break in response to reminders. This further suggested making the technology reliable could further improve compliance.

Compliance with prompts also correlated positively with adherence to tracking (n=15, r=.523, p=.045), which meant participants who were more compliant with the monitoring protocol over the study were also more compliant with the reminder to take breaks. Finally, adherence to tracking was found positively correlated with post-intervention change in self-reported ambulatory time (r=.533, p=.041), whereas compliance was found negatively correlated with post-intervention change in self-reported stationary time (r=-.54, p=.038).

6.4.6 Perceptions and experience of WorkMyWay

A total of 11 themes on participants' perceived acceptability and experience of *WorkMyWay* were identified.

6.4.6.1 Acceptability of tracking

6.4.6.1.1 Theme 1 – barriers to tracking

Participants reported using the system on most workdays, except for 2 circumstances - being out of office and encountering technical issues. For the former, participants were instructed not to use *WorkMyWay* on ad-hoc out-of-office working days and sick leaves, as they were atypical in their day-to-day work and would distort data.

"because often I'm out of the office, like going around the country… coz I'm delivering training at the moment, that wasn't like a typical workday, so I'd leave it behind." -P11, 50% adherence, lowest in the sample

The remaining days of nonadherence were due to technical issues, especially problems with syncing data between the tracking devices and the smartphone over Bluetooth connection. If it were not for the connection problems, most participants, even including those with below-average adherence in the study, found it easy to integrate the behavioural tracking into everyday routine.

"*If everything is running smoothly, it was absolutely fine. So like the last couple of days, it's been perfect."* - P11, 50% adherence

"*I think it's really quite simple to use. You just start and stop. That's how it's supposed work, start tracking and stop tracking."* – P2, 70.0% adherence

"*pretty easy (to embed the tech use into everyday routine). I guess I have a set-up routine when I get into my office anyway, get my laptop out, set up."* – P4, 93.33 % adherence

The email sent by the researcher at the beginning of every workweek was deemed as a helpful reminder to continue tracking, especially after holidays; remembering to set up and start tracking every morning was deemed easy. Participants only found it difficult to remember to stop tracking at the end of the workday, because the automated tracking worked mostly at the background. However, this had consequences on the quality of tracking the following day, because long periods of the trackers logging data in standalone mode could sometimes overload and crash the microcontroller.

"I had no trouble coming in every day and turning it on, but I had a couple of days on which, I went back home with my wrist on me. I was like 'no!' …Once you clicked 'tracking' you forget about it" – P8

Similarly, participants found it difficult to remember to take the study phone with them during short breaks. As the *MetaWear* board embedded in the wrist and cup device were configured to cache data temporarily during short period of disconnection and resend data to the App upon reconnection, the researcher instructed participants only to take the phone with them if they were out of the office for 15 minutes or longer. However, the devices turned out not to reliably reconnect always as expected, even after brief disconnections:

"What was hard was remembering to take everything with me. Obviously this is on my arm. But if I had the phone on my desk and somebody'd be like, 'I need you really quickly'. I would been up and walking about but the phone would haven't been with me." -P10

"I don't know if it would be out of range, so I take my phone when I'm out of the office. But if we just went to the corridor, it was okay to just leave the phone in the office (according to the instruction). Sometimes I don't think it's recorded things like going to the printer and back from the printer for like 10 or 11 times. I don't think it had because it kept saying 'not connected'." – P13

"Most of the time I'd say, when it reconnected, it would just refill the graph. But obviously it's better if you remember to take the phone with you, it would just continuously work, which would be better." - P14

In addition to unreliable connection, the discomfort of wearing the wristband (e.g. too tight, and sweaty in summer) was identified as another barrier to acceptance by 5 participants (P5, P12-P15). As a result, in post-study use where more flexibility was allowed in the placement of sensors, P12, P13, P14 decided to have the "wrist" device fixed to clothes with clips and pins instead (Figure 36).

Figure 36 An alternative way of wearing the tracking device suggested by participants

6.4.6.1.2 Theme 2 – perceived accuracy of tracking

Despite technical issues, most participants thought the algorithm was accurate in differentiating activity and inactivity.

"It's quite interesting most of the time it was accurate. You are like, oh my god I've been sat – you got a red bar - I've been sat for this long already! …so as long as it was working fine and I trusted the data." – P1

"In the mornings I sit down for longer periods of time. I can corroborate that by looking at my data. It's not good." – P3

"I think like 90% of the time (it was accurate in telling whether I'm active or not)." – P10

"They seem really accurate, especially after one update, I can't remember when it was I updated it. After then it felt really was picking up everything. So I felt like it was quite accurate." – P15

Combining participants' reports with system logs, perceived inaccuracy occurred mostly during periods of device disconnection when no data was recorded at all, and only occasionally during periods when the data connection was intact. In the latter case, the detection algorithm could be either too sensitive in picking up movements that participants would not consider as breaks (e.g. opening the window blind, sitting and talking with hand gesturing) (P4, P7, P8), or not sensitive enough in detecting breaks (P1, P2, P3, P11, P14).

"That's why I realised it was quite sensitive because a lot of the stripes were just 1 min. Initially I sat there and thought I haven't been out of the office. What is it recording? Then I thought, oh, I've opened the blind, I've got up and put something in the bin. Maybe actually I haven't physically moved. Then I thought it's logging that I'm typing." – P7

"It (feedback) made me feel really guilty. when you looked at it, obviously it only records if the time you stand up and you are up walking around is more than a minute. So there would be times where I just quickly buzzed across the hall, or more than a few minutes, oh I'd be like 'oh, that was counted for something.' Then it wasn't counted for anything. Because I have literally gotten up and gone next door" – P11

The issue was rectified by adjusting the detection thresholds upon individual requests. In the weekly reminder emails sent to all participants, the researcher explained that she could help make the break detection more or less sensitive based on each individual's experience and preference. 3 participants (P4, P7, P8) requested to have the threshold raised so that the break detection became less sensitive.

"They got more accurate when you gave me new settings toward the end. Because sometimes it would say I was active but I was just in a meeting. I think I moved my arms too much. but if I walked around the building, it was always accurate to catch that." – P4

"Right at the beginning, it was too sensitive. I was just articulating with gesture, but it would record it as a break. then I talked to you...if you remember, I had problems with the data not being sent, you restarted it and did something, you also changed the parameters, the last time. After that, it was no longer doing that." – P8

6.4.6.2 Experience of troubleshooting

6.4.6.2.1 Theme 3 – efforts and resources required for troubleshooting

The researcher provided each participant with a one-page technology instruction that included a 5-step procedure for troubleshooting connection problems. Participants found the instruction itself clear and easy to follow.

"It's easy to get involved in and not difficult to understand. We did look back on the sheets a few times to check some stuff and what we can actually do to troubleshoot things." - P14

However, the troubleshooting steps were only occasionally effective and needed to be performed in the exact order specified. As there was a delay in revealing whether the data connection was recovered after performing the troubleshooting steps, the lack of transparent feedback during the wait confused and frustrated participants.

"Sometimes I've been walking around and moving my wrist, and say, 'hey, I'm waking, why don't you show I'm active?' But then you wait, then I realised that, if you wait a bit, it will show that…It was frustrating I didn't know what I did wrong. If I knew, for example, if I was moving my hand too much, I need to wear it correctly, then I would have changed it. But it seems to be very random." – P8

Hence, participants, especially those lacking experience and confidence in using novel technologies such as the *MetaWear* trackers, counted on the researcher for troubleshooting, in which case the close location and accessibility of the researcher was a significant facilitator to promoting adherence and quality of tracking.

"I used my phone to the basics. It was really handy having you in the building, just sending you regular emails." -P7

"I'm not very good with technology generally…I tended to think, all well, I'll just put it on my wrist and this bit (the study phone) in my pocket and I'll look at my flashing thing here and I'll let you get on with the rest." – P5

Participants confident in using novel technologies (e.g. P4, P6 and P8), in contrast, would repeat the troubleshooting steps, which, however, was deemed time-consuming and potentially disruptive to work.

"*In the morning, sometimes there was struggle to connect the devices to the mobile phone. There was a few days where it would take 5 or 10 minutes of waving it, and going and then check it. And then it wasn't working, shutting down the App, cutting down the Bluetooth, booting up the phone…that's a bit of barrier to actually using it.*" – P6

Fortunately, the experience and effectiveness of troubleshooting got better, as the study went along and that the researcher and developer understood more about the Bluetooth technology, improved the system, and delineated the troubleshooting procedure.

"…but it feels actually as if it's got better as it's gone along, so I'm assuming maybe you've made some tweaks, as people have caught you out." – P7

"Once you explained to me to update the settings, I understood all of them – that's what I need to do. Coz in the beginning, I only turned off the Bluetooth, and turned it back on and hoped for the best. But understanding that there is other ways of doing it, that really helped. I got it working quicker than before...If I had continued it, I'm not as worried now as before... Now I've got that knowledge through using it, especially you said it's probably sending stuff to the phone… That was my main thing – I wanted to see what was going on." – P12

One of the improvements was to make data problems more transparent. In the initial version, invalid tracking periods (0 counts for 10 minutes or longer) were undifferentiated from inactive periods in real-time processing and would count towards the total inactive time. However, there were at least 2 disadvantages of this approach.

First, as data problems occurred so frequently in the early part of the study that participants became annoyed by the persistent presence of long red bar in their graphs and red lights on their vessels, despite that they had constantly tried to troubleshoot and take breaks to test the connection. As a result, they lost trust in the system and ignored feedback presented by the system.

"because some days I just had a big red block like hours, and I thought that can't be right… it shows me inactive during a lunch break. that's odd because I normally go for a walk at lunch time…toward the end of the study, it was the technology problems I had… I guess it was probably a 'trust' thing - whether the device is actually working as it should be." -P2

The second drawback of this approach was the difficulty with diagnosing connection problems. With the initial design, the user would not ascertain a data problem unless s/he took a break to check whether that was registered; by the time they found that out from a break and notified the researcher, a long period of data loss had occurred.

Hence, a major user experience (UX) update was implemented to represent invalid tracking periods as empty space in the timeline and trigger a phone notification when no accelerometer count was received for 10 consecutive minutes. The system did not notify the user of shorter periods of disconnection, to avoid disturbing and worrying the user after every short break where temporary disconnection was normal. This change enabled more timely detection and troubleshooting of data connection problems.

6.4.6.3 Fidelity, acceptability and mechanisms of impacts of the prompts/cues component

6.4.6.3.1 Theme 4 – fidelity of prompt delivery

Interviews suggested the prompts/cues component delivered with the LED reminder device (variably called "cup device", "light" in interviews) were not always received by participants exactly the way as intended. The fidelity of delivery was dependent on 3 factors, the visibility of the reminder, the portability and placement of the reminder device, and the reliability of Bluetooth connection.

First, a lack of attentional resources at work to notice the subtle reminder was identified as a barrier by about half of the participants. In addition, several participants (P4, P6, P14, P15) reported accidentally putting down the vessel with the LED facing away from themselves.

"Sometimes the mug was on my desk facing away like that, I would be working. and suddenly I sort of thought, ah, I've been here a long time, I looked at the phone and it had been 75 minutes. then I looked

around on the phone and the light on the mug was flashing over here, coz I just didn't have it faced the right way" – P4

"Occasionally I would turn around to look at my bottle and found that I had turned it away from me unconsciously. Then I'll turn it around and find it flashing." – P6

For others, even if the reminders were positioned within the field of vision or in the periphery of attention, they might not notice it if they were concentrating on work.

"*But even if I'm working like that, I'm right now not looking at the light. It's below (the screen). Maybe if it was stuck in my screen, it would be different." – P8*

"I think I had it too high on the glass...If I'm typing, I'm looking down, I don't look at the screen, I can't touch-type…I think if I would do it again, I would have the notification thing more to what I'm doing." - P12

Secondly, although the intention was to have prompts/cues delivered with an interface attached to an everyday cup/bottle/glass that plays an important role in many' office break activities, not all participants followed the instruction to attach the LED reminder to vessels that they would use for everyday hydration needs. For example, P5, P7 and P9 normally placed the reminder to one vessel while using another vessel for everyday hydration, because the device was too "chunky".

"But it's not in a good place on a cup really. It gets in the way. So I tended to use a different cup." – P5

"But as I go to other campuses, then I wouldn't take the cup. Although I started taking the LED, but to be honest, sometimes it was in the bottom of the bag." – P9

Last but not least, the unreliable connection between the cup device and the smartphone, on top of the unreliable wrist-smartphone connection, badly compromised the fidelity of prompt delivery and even adversely impacted on behaviours.

"*Although it is there, if it's not connected for some reason, it doesn't always light up.*"– P13

"*There were a couple of days where I didn't realise and I probably went through sitting, because it wasn't showing…" – P9*

"It's only at times when the light didn't come on and the phone didn't buzz, I checked the phone and swiped to see what the time was and I realised I hadn't been up for last hour." – P12

Ironically, in order to be prompted, participants had to proactively check the App from time to time to make sure the cup device was connected. As a result, some reverted to the App for real-time information on sitting time directly.

"Coz I think there were a few little glitches... I didn't realise it wasn't working until I had a look... which is why I then moved to checking on the phone, coz you can't always tell with just the glowing. The light was useful, but actually sometimes I found it's quicker just to see on the App." – P9

6.4.6.3.2 Theme 5 – attitudes toward embeddedness

Individual differences existed with respect to the preferred medium and modality of prompting. Some suggested a vibratory or audible reminder delivered with the wristband would be more noticeable, whereas others preferred the current visual one or were unsure.

"I like the wrist band, because it's more autonomous and if there was a way that could buzz say vibrate to have a break." -P1

"I got a Garmin that buzzes every time I need to get up and move, but when I'm at work, I'll have my watch on 'do not disturb', which kinds of defeats the purpose. …This (cup device) was a more subtle way of saying, 'you need to get up', as opposed to go out buzzing that's really disturbing to your surroundings. I really like having the visual cue because I feel like it kind of took my attention away from what I was doing and made me physically look away from what I was doing." – P11

"I'm not sure. I'm in two minds. Coz I was gonna say that it would be useful for me to kind of noise, almost vibrate or buzz or something like that. if it is 2-hour meeting, and I forget to turn it off…if you forget, then an hour in, it starts making some annoying noise." - P15

The embeddedness of prompts/cues within an everyday break-related object was perceived and experienced differently by participants. The idea was to allow participants to attach the LED reminder device to a vessel that were used during breaks and associated with the break action and the goal to care for one's own health. For some participants, this approach made a lot of sense and worked well to prompt and facilitate breaks. As a positive side effect of this medium of delivery, some participants (P1, P2, P3, P12, P14) also reported drinking more liquid:

"Because it reminds you to do something. You can very well take it as an excuse to fill up your water bottle, or take it and drink it and then fill it up again. It worked for me in that way." – P3

"I did find actually that it made me probably have more drinks and water than I would have done normally. It's been good in that way…" -p1

"It was good to make me drink more rather than just get up, coz it gets me a reason to go to the kitchen and fill my bottle. If it wasn't attached to a bottle, I might not have taken that with me. I'd just go for a wander. So that was good." -P14

When prompted in interviews, most participants would appreciate the addition of a technological feature that tracked, visualised and prompted hydration behaviours.

"That's a good thing to incorporate, especially with it being on a cup because it's important to stay hydrated throughout the day. That's a nice thing to have." -P2

"I think that's interesting for me, just because I know that I didn't drink enough water. So it was a nice little extra thing to make sure I did drank." – P14

However, a few participants held less favourable attitudes towards this medium of prompting:

"For me even though the glass is there, I will use it in the break, it's not the thing that reminds me of a break. Before having used it, I didn't realise. I really thought the glass would remind me to take a break. It's actually the device with the light that would remind me to get up...I would have to have it close to what I was doing, as I don't touch type…It could be something to do with a break, but not on the thing that you take for the break." – P12

Quite a few participants suggested combining the wrist and cup device into one, or even eliminating both devices and using the smartphone for both tracking and prompting, in order to make the setup routine easier. Participants felt tired of managing multiple devices, partly because of the unreliable connection between the cup device and the smartphone, on top of the unreliable wrist-smartphone connection.

"Maybe just having one device or one thing embedded in an object that just all works together as one. That'll be much better than having all the individual things." – P2

"Maybe it would be better if the reminder was somehow in the device you wear on your wrist. That would be less thing to worry about." – P5

6.4.6.3.3 Theme 6 – perceived influences and mechanisms of impacts of prompts

Despite various factors compromising the fidelity of delivery, participants reported the LED reminder did change their behaviours in different ways. For some, the lights served to direct their attention from work to the need for breaks, and bring awareness to sitting time, echoing questionnaire findings that suggested a decrease in perceived difficulty with keeping track of time and remembering to take breaks (i.e. prospective memory).

"So the reminder - that 45 minutes actually feels like a very short amount of time, but when you are sitting for 45 minutes, for your body that's a quite long time - makes me aware of the amount of time I've spent sitting where I could possible get lost in tasks and quite happily sit for 90 minutes, which is really bad." – P6

"for me it was like when the light came up, I think 'ok I need to take break'. If I was in the middle of something, I tried to finish it, and then go and take a break." -P15

Furthermore, some participants (P3, P6, P12-P15) actively used the LED to support their action plans or implementation intention, which was an intended mechanism of action:

"I guess I would see the green as a warning in that I should probably do a bit more work on the paper for example while I'm in the flow, but soon when a good point arrives, I should stop and go. when the yellow one comes on, I would be more in the frame of mind of 'I'll just finish this sentence' or 'I'll just send this email and then go' or 'I'll just finish this one little job and then go get a drink'. and then with the red one, when I saw it, I tended to just stop what I was doing and just saying, 'just put stuff down' and pick up my mug and go get some water or coffee." – P4

"If I was stuck in a task, the amber light, I would just let it go, til the red, more insistent, and the final stage, the flashing red came on. If I did have the time, if I was in between tasks, I would make an effort to go and fill my water bottle, just go for a walk to the atrium and back, just to get up and about." - P6

It was assumed that participants might develop an automated or semi-automated response to the LED reminders if they repeatedly take breaks as soon as the LED was on. Hence, the post-intervention questionnaire assessed the automaticity of "taking a micro-break whenever the LED is glowing", in addition to the behaviour of "taking regular micro-breaks throughout workdays". Score on the former (mean=3.4, SD=1.238) was significantly lower than the latter (mean=4.85, SD=.441), based on paired-samples t-test (t=-4.794, p<.001).

This was echoed by the interview finding that most participants tended to think their current responses to the LED were still driven by conscious decisions rather than automatic, unconscious, impulsive and uncontrolled processes. However, the quotes also suggested that the LED did seem to automatically activate (i.e. similar to the "priming" technique used in social cognition research) some kind of a mental representation that drove people to stand up sooner, although this goal-directed action schema often had to be inhibited because of a higher priority work-related goal. Nevertheless, the quotes demonstrated great promise of the LED in activating break-related goals and potentially instigating unconscious goal pursuits.

"On some days I'm really busy, and I would wait. But my first instinct would have been to remind myself, 'oh I have to get up and I have to do something'." – P3

"There was one or two cases where I was in a meeting and I couldn't get up. But (otherwise) if it flashed, I would do it. I found that quite difficult not to." -P12

"If I see the light, I would be straight up" – P14

If participants use the technology for longer, the impulse to react to the LED will likely be stronger:

"…this isn't automatic for me yet, but it's a nice reminder…it could be, If I keep using it, I guess, as soon as it goes, you could be like, 'ok' straight away. But at the moment, it feels a bit more like a reminder for 'ok right, I need to take a break soon. Let's finish this. Just get to a good point.'" – P15

There was also suggestive evidence for evaluative learning of the colour-coded LED and on-screen feedback. Participants came to like "green" and dislike the "red" and "orange" presented by the technology, potentially because the colours were repeatedly associated with healthy and unhealthy days in the system feedback respectively; or it could be the case that the pre-existing associations of these colours with positive/negative things in everyday life have facilitated the interpretation and persuasiveness of the feedback. As a result, it seemed to be those immediate affective responses toward these colours, rather than deliberation on long-term health benefits, that had driven and energised break actions at points-of-behaviour:

"Obviously you don't want any red, do you? I like the yellow and green. If I see a day that's like yellow and green, I know it's been a good day. It sets me up for my mood at the end of the day." -P11

"*It was lovely to see the green. The lesser the orange, the green quite frequently, that was quite nice to see. In a way, it was a reward to think, 'oh yeah, look, I've done this this.'…When you got oranges, you sitting down more, it can't be avoided, but I was consciously thinking I've been sitting 1.5 hour now, I need to get up and move about. I started to get a bit jittery."* -P13

"We had different stages of flash…So before the flashing, I was trying the 'beat' it really. Yes. I set myself a little challenge to have a micro-break before that stage." - P2

In addition, because of the technological problems that hindered reliable delivery of prompts, an unintended mechanism of impacts seemed to occur – instead of waiting to be prompted after 45 minutes, participants internalised the rhythms and checked sitting time regularly. In this case, the physical presence of the technology worked as a constant cue for behaviour, whereas the coloured feedback and LED served to negatively reinforce[6] the self-checking and timely break behaviours.

"Something in me that just said, you've been sitting a while, let's see if it's blinking and I turn it around, and it was…if it's not blinking, it was in my field of vision, really, my periphery, so come back to me." – P6

"*We were quite aware that we haven't moved for a while, before the reminder went off. They would check the phone, and say, 'ops, I've been sat for 30 min. Shall we go and have a walk there?' And then we would. So it wouldn't have the chance to go off." – P14*

Participants also discussed potential carryover effects of the reminder after it was removed at the end of the study:

[6] Negative reinforcement: reinforce a behaviour by removal of an unpleasant consequence contingent on performance of the behaviour

"I think once you get into the routine of looking up every hour, and go 'ops, it's time to get up and move', then you almost don't need it. But it's a nice reminder. If I had that for a couple of months, and then do without it and see if continue that behaviour, or if I go back to normal." – P11

Inspired by this alternative strategy innovated by those participants, in the later part of the study, the researcher adjusted the BAP protocol to more explicitly guide participants into forming action plans in the form of *"I will take a break, before it reaches…minutes, while I'm [task: working alone/meeting/working on a deadline]…"*, instead of *"I will take a break if the light is glowing/flashing in red"*.

6.4.6.4 Other App features: real-time feedback, history, goal setting, rewards

6.4.6.4.1 Theme 7 – real-time vs. end-of-day interaction with the on-screen feedback

The *WorkMyWay* App visualised stationary and active time along a colour-coded timeline, both in real time and retrospectively in the "history" section. Although it was intended participants left the App running at the background throughout the day, some participants frequently opened the App for actionable information throughout the day, mainly because the LED reminders were not reliably triggered. Indeed, the real-time on-screen visualisation was mentioned as the most interesting and valuable feature by all participants.

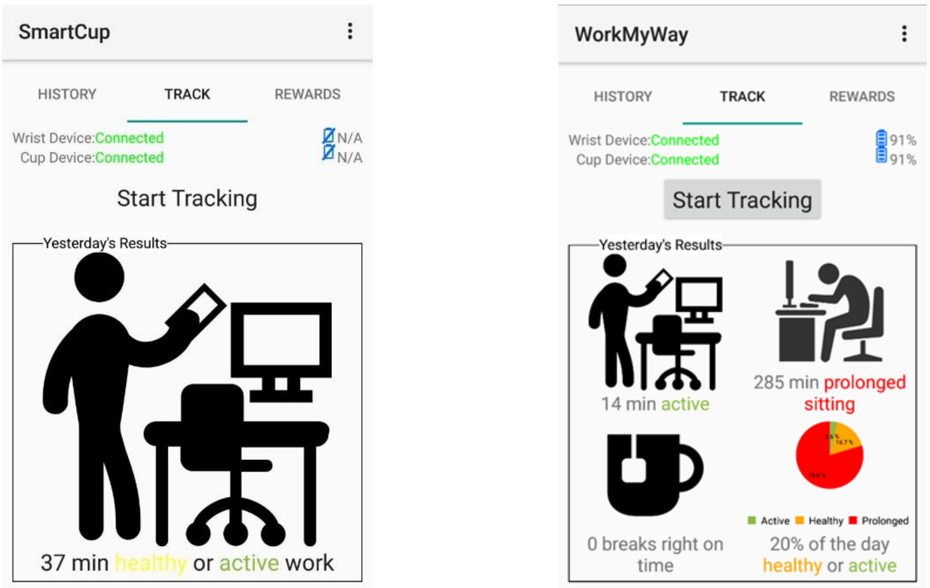
"Sometimes it's really hard to know how long you've been sat still for. You think it's really short amount of work because you've been engrossed in work. then you check your phone, you are like, 'on my god! I've been sat here for ages.' You just don't realise." -P15

When asked about their opinions on the "history" section (as opposed to real-time visual feedback) in interviews, participants said it was useful to have the "history" that allowed them to review and compare data on different days, but the frequency and depth of engagement with the historical data differed across participants.

"When I stopped tracking, I had a look at the history and compared it to previous days, which is interesting." -P15

"I looked at it, but I might not have taken it in so much. It's nice to see it, like compare it to yesterday, how have you done. But I don't really take it massively in, unless you finished and you went 'that wasn't a very good day'." -P14

"I didn't do it. I just didn't have enough data or figured out I did have that…I just used it in real time, rather than thinking how did I do. It had passed, I couldn't change it. I don't think it's my interest to look at that either." – P12



Original design Revised design

Figure 37 Changes to the layout of the summative feedback in the App

Moreover, some features in the "history" section had a limited exposure, based on interviews with Phase I participants. Although most participants took a glimpse at the summary box that was displayed below the 'start tracking' button each morning (Figure 37), not all participants were aware that they could actually swipe the box to view different metrics. Therefore, an update was implemented after Phase I to make all the summative metrics displayed on one screen without the need to swipe, which greatly improved the exposure of those contents.

6.4.6.4.2 Theme 8 – gains in memory, awareness, and motivation because of the colour-coded feedback

When prompted in interviews, all participants said they appreciated receiving feedback on their daily behaviours. Interview responses suggested a variety of potential mechanisms of impacts.

Some used the daily feedback merely as a tool for self-reflection, without an explicit intention to use the feedback for behavioural regulation. They enjoyed using it because they could relate to the data and link the feedback with personal experiences on different days.

"In the mornings I sit down for longer periods of time. I can corroborate that by looking at my data. It's not good." –P3

"Sometimes when it reaches 5 pm. you are drained, mentally. you are like, 'why am I so tired?' …then when I went back to the App and I saw that 'yeah, you've done everything but it took you 2.5 hrs sitting down, which has consequences later on'. It's gonna drain me. For me, I used it as a proof you weren't taking care of yourself." - P8

Consistent with findings from the questionnaire data and as an intended mechanism, feedback on behaviours enhanced retrospective memory of daily sitting and break patterns, which made them come to consider prolonged sitting without breaks as a health issue and raised their awareness of it:

"I think it just made me more aware that I was not getting up, not go to exercise, go all day without a drink. Even knowing how many times you are getting up, being more aware. I could have gone up and done to the printer and not being aware of how many times I was doing it. But now I've got an awareness." – P13

The mere fact that behaviours were monitored could also have an impact on behaviours:

"…knowing that the data is recorded and you can see it. It's like, 'well, actually if I don't go for a walk today and I've sat down for almost 8 hours. Then I can see my own data and it's like, wow, that's really bad!' so that's the motivation to make sure that you are doing it..." – P10

Other participants took a further step to use the feedback as a motivational tool to purposefully regulate behaviours and pursue goals.

"I think I tried to be better because of the feedback. It's kind of concerning to see the red. I think the colours specifically. You see a lot of reds and you are like, 'em, I don't want that. I want green and yellow.' I looked at my feedback right before I came here as well, so I was like, 'oh it's been a good day today. I've been really good about getting up and taking my breaks.' It has made me better." -P11

"*so if I saw a day like this (with only green/yellow blocks), I'd be very happy, because this would make me feel like I've had a good amount of breaks. I felt like this was a productive day, whereas …even this day looks quite good. I know it's red. It's probably not that long…I tried to avoid red.*" – P15

On the face of the above, participants self-delivered the additional BCTs of "self-reward" and "remove punishment (negative reinforcement)" based on the colour-coded feedback, which seemed to be even more motivating than the explicit rewards presented by the system in the form of "trophies" and "badges".

"*I spent most time just looking at the blocks of bright red more than I looked at trophies.*" – P4

"Then you could easily base it on, okay, I did this yesterday, I will do more... really I think for me the visual impact was the thing, seeing that you got all greens." – P13

6.4.6.4.3 Theme 9 – format and framing of automated tailored feedback

Regarding the preferred forms of on-screen feedback, visual (colour-coded timeline and pie chart) was liked by most participants, followed by textual (the "congratulations" text together with badges) and numerical feedback (e.g. "x minutes of active, prolonged sitting"; "x breaks right on time").

"I like the visual representation, so you could clearly see, coz it was colour-coded inactive and active, that was really good. That's a very clear indication of your activity. You can see straight away if you've got a big red block, you know you've been inactive. So I like that. That was good." -P2

Participants also discussed how the framing of feedback in the App shaped their thinking with respect to what constituted good versus bad behaviours. For instance, the fact that any interruption of 1 minute or longer in stationary time was captured and coloured in green in the graph changed people's perception of what counted as a physical activity break in the workplace, and in turn enhanced people's self-efficacy for breaking up sitting.

"It actually showed me how much I was moving. So my perception was that I sat here for hours, coz some days it feels like that. But actually the green bar show you I'm physically moving more than I thought." - P7

"Also the other thing has been actually to recognize I do naturally take breaks just by moving between activities. So it is a part of my normal day anyway, when I have to move between meetings anyway." – P9

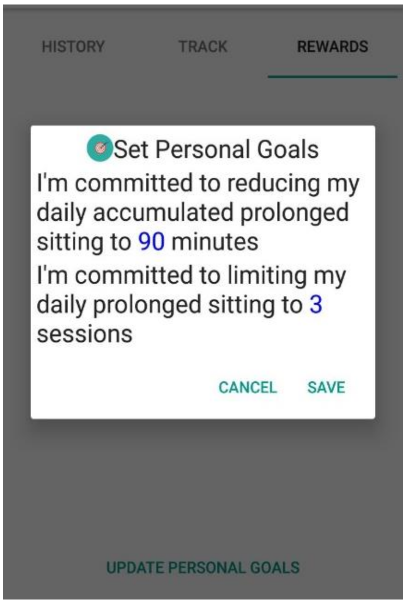
Similarly, because of the way the metrics were calculated and presented in feedback, the system seemed to penalise sitting bouts that exceeded 60 minutes, but not total sitting, and reward timely breaks that were taken after 45-60 minutes of sitting, but not other types of breaks:

"That was a shame. 1 hour and 1 minute, I almost did that one. I could have got an extra trophy…but again see I was only naughty for 6 minutes. but that's producing 30% of the pie chart from going 6 minutes over. Seems a bit unfair…It says 'breaks on time'. So I shouldn't take a break every 20 minutes. That's a good question. is it better for you to not take too many breaks?" – P4

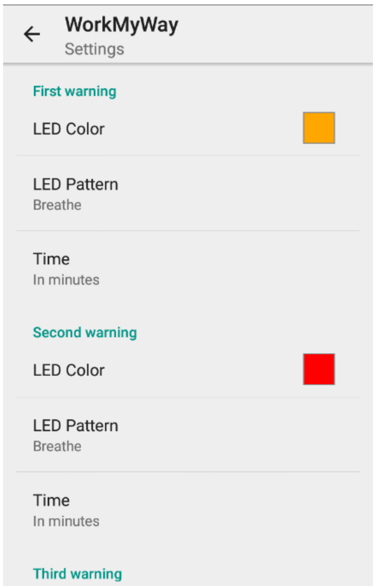
The least used function in the App was 'goal setting', as 9 (60%) participants did not update their goals at all throughout the intervention period, 4 (26.7%) updated it only once and 2 (13.3%) updated it twice, based on monitoring data:

"I did update it at one point, coz originally I think I had it so that I didn't want to do more than twice longer than (90 minutes). I think I reduced it after a few days to make it saying 'I only want to do 90 minutes once'. But actually I don't think I looked at this tab for 3 weeks. It's interesting I looked at all of these data with the number of red blocks in it and yellow and green. but I didn't spend much time looking at the trophies or goals." – P4

The interview responses suggested a potential reason for low engagement with goal achievement was that the goal defined in terms of daily cap on accumulative prolonged SB was way too complex to be remembered. There was incongruency between the goal framed in the intervention and that in participants' mental representations, as when prompted with the question *"how often did you update your goals?",* most participants' immediate responses were about how often they updated the reminder intervals (Figure 38 right), instead of what was set up as goals at the briefing session and in the App (Figure 38 left):



Intended "goal setting"



Perceived "goal setting"

Figure 38 The "goal" framed in the intervention versus the "goal" perceived by participants

"*I kept it as it is because I was happy with that goal – that's something I'd like to maintain – to break every hour.*" -P2

"*I think I did (change the goal setting) at one point. No, I didn't. I forgot about that...I changed the warning. I kind of saw that as like a goal.*" -P4

This partly explained why participants were not particularly motivated by the "badges" indicative of goal achievements in the system.

"Trophies" were awarded on days healthier than the previous valid tracking day. Interest in the "trophies" varied across participants. Some were really motivated by both trophies and badges (P10, P13) throughout the study, but the majority were only excited to receive them at the beginning. The excitement wore off towards the end of the study, partly because it got increasingly difficult to receive trophies, and partly that the reward rule was occasionally perceived as illogical.

"*It's one of those little things that keeps you interested in it. It means you've done it on time, or you are healthier than yesterday, rather than having to go back yourself and check the history…But then we don't really get any more rewards, we were all like almost give up*" -P14

"But even though I had bad days, I still got badges sometimes, which I don't understand." – P8

6.4.6.5 External factors

6.4.6.5.1 Theme 10 – organisational climate and job constraints

All participants in the study thought the university and the departments they worked for were happy with the behavioural target (i.e. hourly break) promoted by the technology and permissive of employees' personal use of technologies as such, which was also why they could participate in the study in the first place.

"I think this workplace will be happy with it, it's a very flexible university, or it's a flexible department…there is a lot of trust and independent work in timing. I don't think people mind if you get up to go to the bathroom in the middle of a meeting, and things like that." – P4

However, there were some constraints on break behaviours placed by the nature of the work and the relationships with others involved in the job role:

"But because of the nature of roles, the period of breaks may have to be a bit more controlled. So like student-facing, student services, they have to be there for particular times, so the breaks are gonna be structured around of their availability and around other's availability. So the implementation should be quite carefully thought about." – P9

Different views existed in regard to who should be held accountable for employees' behaviours that occurred in the workplace and that had consequences for personal health.

Some thought the organisational and management had an important role to play:

"I think it should be encouraged. I think it really would rely on who's head in the department as to how encouraged it would be. I think it's something that we should all be doing within the university. Because we should be doing exercises. We should have lunch time exercise session. Because you get very sluggish, when you've done half day work. It's quite tiring. In the afternoon, if you miss your lunch break, you do get very tired...It would be good to bring it on the department's head, if you could encourage them to do it, take it on board"- P13

However, the majority held the view that it should be down to the individual to take care of themselves and to choose the appropriate tools, but it would be nice if the organisation could offer some options.

"That's interesting. I mean it's everybody's own responsibility, isn't it, to make sure they are taking enough breaks? But it's not always possible. I mean if you are in a meeting, there is a lively discussion going on, you probably wouldn't be able to get up and walk around. I wouldn't take on the responsibility of anybody else's device flashing and say (you) ought to move. I think everybody got to do that for themselves." – P5

"I think the organisation doesn't really mind, care either way. They really leave it up to the individuals. So they don't mind if I would want to put something in place to help me. But they also don't care in making it different for people. It would be nice if they would have some options that we could use. I don't know whether that's where this could go. Then that would be nice to use. As an organisation, they do encourage people to walk around, but not this type of technology. The breaks, yes, they are very happy with when you take breaks. They do want you to think about health. But It's really up to the individual to decide what to do, which is of course important, because as individual, you need to pick something that suits. This could suit me." -P12

Encouragingly, one of the participants who was a senior manager participated in the study with the interest to source an intervention that could be taken on board and scaled up at the university to improve staff wellbeing:

"As I'm the wellbeing lead, anything that encourages staff to take a practice at work, I'm keen on understanding…(if) you got some summaries of if people actually found it helpful, I'd be quite keen to promote it to university." – P9

6.4.6.5.2 Theme 11 – interpersonal influences on adherence and compliance

The subjective norm, or the perception that a majority in the workplace are trying to take regular breaks, was identified as strong motivator to both using *WorkMyWay* and performing the promoted behaviour.

"It's a nice environment in that. People are often going out to make a cuppa or asking somebody. Yeah. I think we are all very aware of sitting down all day. I think generally people encourage everyone in there anyway, which is good." -P10

"definitely positively. My department is very…they are all occupational therapists and physiotherapists. They are all get up and move. It's welcoming environment for that kind of thing. Everyone is very conscious of that. Like if we've just had an hour of long meeting, let's have a comfort break, get out, stretch your legs and come back. So that's quite good. -P11

Direct social interactions both facilitated and hindered use of *WorkMyWay* in different contexts. On one hand, most participants had to stop using the reminder device in formal meetings where breaks were not always possible.

"When I was in a formal meeting, it was more embarrassing then because I didn't know how to stop it flashing apart from taking it off and putting it in my pocket…But it could be a social reminder. But it depends what people think is an acceptable meeting. Some people think 2-hour is a perfect thing, I don't think any meeting should be longer than 30 min."

On the other, when a participant did not notice the LED reminder, there was the chance that co-workers who happened to see the LED flashes could remind him/her:

"Some of them that didn't know would come past and say, 'oh, what's that thing flashing?' and then I explained. And then they'd know. Next time, they'd be like, 'hmm, it's gone amber or whatever', coz sometimes I was so focused on the task in hand that I hadn't noticed that…Yeah I think it was really good how everybody else kind of gets involved in an office environment." -P10

The physical artefact of the technology also turned out to be a conversation piece to get people talking about wellbeing in the workplace and sometimes prompt them to take a break together.

"They would go, 'oh what's on your water bottle?' 'Oh, I'm part of a study'. So they were interested and it got them talking. So that's quite good. But then someone I work with in office could sometimes see the light when she was over at my desk asking me a questions or anything, she pointed it out, and we'd be like, 'oh, maybe we should go get up!' so it prompted both of us to go, get up and make some tea, or do something. So that was quite nice." – P11

For P12, P13 and P14, participation as an office team enabled so much fun in the process and potentially enhanced the usage and effectiveness of the intervention.

"That was just so much better. Because we were all in it together. We all had issue. We would sort it out. If P14 (anonymised)'s is flashing, she wants to get up, and we all go together for a drink or whatever." - P12

"It was a reward to think, 'oh yeah, look, I've done this this. I showed my colleagues. Have you done this?' and we compared it." – P13

"They would check the phone, and say, 'ops, I've been sat for 30 min. Shall we go and have a walk there?' And then we would."– P14

6.5 Discussion

The following section will discuss direct results on feasibility and acceptability of *WorkMyWay*. A broader discussion of the study results in relation to research questions set in Chapter 1 will be discussed in Chapter 7.

6.5.1 Principle findings

This is the first study to evaluate the feasibility and acceptability of a theory-informed, multi-component workplace sedentary behaviour intervention that involved the delivery of prompts and cues via an interface embedded within an everyday object and connected to wearable activity tracking data. A mixed-methods approach combining system logs, activity tracking data, questionnaire responses, and interviews sheds light onto multiple aspects of the research and intervention processes.

The findings suggest broad acceptability and promise of the intervention contents and technological approach. Among a convenience sample of 15 participants working in a higher education office-based setting, attrition was 0%, mean adherence was 83%; no significant changes were observed in technology-captured or self-reported physical activity, stationary or ambulatory time, though significant improvement was found in self-reported break memory and automaticity. Qualitative data showed that participants were favourable towards the intervention and reported using the technology to develop behavioural insights and regulate behaviours. Diverse attitudes existed toward the LED reminder – some found the component particularly interesting, useful for creating sitting awareness and potentially beneficial for encouraging hydration behaviours, whereas others disfavoured the medium of delivery because of the system complexity and burdens imposed by the extra device and connectivity. Despite frustrations with frequent technological problems, the majority (n=11) intended to continue using the technology after the study; 5 of them did not abandon the technology until 3 months after intervention commencement, compared with a previous study where all 13 participants stopped using activity trackers within 3 months (Boulard Masson et al., 2016).

However, the study highlighted a few technical and methodological issues that made the current version of the *WorkMyWay* system not particularly suitable to move forward into larger-scale evaluation. An average quality of tracking of 68% means with every 3 days of use or so, one day would be invalid. Significant engineering and redevelopment efforts, preferably on an alternative platform to the *MetaWear*, are required to address those issues and create an implementable version of *WorkMyWay* for future studies.

Unreliable Bluetooth connection was the first and a most significant issue because of its frequent occurrence and severe consequences. It, first of all, adversely impacted on the fidelity of the feedback and prompts/cues delivered to participants. Problems synching data between the wrist device and the smartphone induced noise to the activity data that was used to generate feedback and trigger prompts. Disconnection between the reminder device and the smartphone added to the issue, as the App could not actuate the LED over Bluetooth even if the recorded sitting time had exceeded the threshold. Secondly, the connection problem hindered efficiency of research data collection. A quality of tracking of 68% meant that with every 3 days of investment of a participant's and the researcher's time, there would be 1 day on which the data was unusable. The issue seemed to reoccur inevitably every now and then. Although the troubleshooting was effective, it required a high level of competence and confidence in technology and imposed time burden. Last, even for the valid days included in analysis, invalid tracking periods for up to 3 hours a day could still distort the key behavioural outcome measures. Indeed, interviews suggested participants possibly lengthened sitting episodes during periods of data disconnection as a result of either being misled by the absence of light or distrust of the always-on light. Combining that with the fact that the objectively captured stationary time was much lower than the self-report, it was most likely that the participants were stationary during those periods classified as invalid and that the connection problem should have caused underestimation of stationary time.

The second issue concerned the physical design and placement of the reminder device. Considering the feasibility nature of the study, instead of giving each participant a smart cup with the LED encased, the researcher 3D-printed a rough case for the LED device that could be attachable to any vessel using Velcro tapes. This might have saved production time and made *WorkMyWay* suit a wider range of target groups who have different preferences on drinks and vessels in the workplace. However, the flexibility induced the risk of participants attaching the device to any object or no object at all. The roughness in design also cause some reminders to be unnoticed because of facing away from the participants. Now that the study has testified to the broad acceptability of a connected and embedded medium of delivering break prompts and uncovered several flaws in the design, collaborative work with professional product designers is deemed worthwhile.

Last but not least, the study sheds light onto the digital delivery of the "goal setting" BCT in the context of SB intervention. Previous interventions guiding participants to set up goals in terms of specific actions on a regular basis or triggered by certain contexts, have proved effective in reducing sedentary behaviours (McGuckin et al., 2017; White et al., 2017). In contrast, in the current study participants did not engage with the goal setting component to a great extent. The "goal" framed in terms of daily cap on prolonged siting was perceived as too complex. Future research is warranted to identify better metrics for summarising daily performance on SB reduction that could be compared across days.

Despite the above issues, the *WorkMyWay* intervention has great promise to become a successful behaviour change intervention. Participants reported the use of *WorkMyWay* was overall manageable in everyday work and the visual feedback mostly accurate, valuable and engaging. Although the study design could not afford efficacy evaluation, the data suggests *WorkMyWay* has the potential to change behaviour via both intended and unintended mechanisms of impacts. For instance, questionnaire and interview responses suggested post-intervention gains in awareness of prolonged sitting and memory of break patterns, both in the situation and retrospectively; participants also reported break decisions becoming more automatic. Most participants were content about the perceived reduction in sitting and increase in awareness over the study period. Individual differences existed in patterns of behavioural change over the 6-week intervention, with a trend of significant decrease in prolonged stationary bouts observed in some and increase in others. Formal studies with a larger sample and longer terms were needed to reveal different change patterns and identify personal characteristics predictive of behaviour change.

6.5.2 Strategies to promote acceptance

The study identified the following main barriers to accepting and using *WorkMyWay*: (a) technical issues with Bluetooth connection and data synchronisation (b) time burden imposed by the setup and troubleshooting (c) the discomfort of wearing the wristband (d) chunky design and a lack of portability of the cup device (e) constraints of job and certain work contexts where breaks were unfeasible.

Main motivators and facilitators to ongoing use were identified as (a) perceived gains in cognitions and behaviours enabled by the prompts and feedback (b) readily available in-person technical support (c) clarity of technology instructions (d) ongoing improvements to the system design in response to participants' feedback over the study (e) positive subjective norms and organisational culture about break-taking behaviours.

These findings point to several strategies to enhance acceptance of interventions similar to *WorkMyWay*.

1. Make the data syncing between different devices reliable and effortless for the participant
2. Improve the physical design of the cup device, possibly by making it an LED ring surrounding a vessel visible from all direction.
3. Incorporate feedback on and prompts for hydration behaviours
4. Improve the physical design of the tracker and allow flexible way of wearing
5. Harness social influences and organisational support

6.6 Conclusion

The intervention appeared generally acceptable with highly perceived value and promise for promoting healthier work break patterns. It is potentially implementable in office-based workplaces, but a significant amount of development work needs to be done. A detailed discussion about the study limitations and implications for future work will be provided in Chapter 7 – section 7.3.

Chapter Seven

General discussion and conclusion

7.1 Introduction

This thesis aimed to advance our knowledge of how to encourage office workers to take regular breaks in sedentary behaviour (SB) at work with the support of Internet of Things (IoT). Chapter 1 has established the significance of the research and set out to tackle the public health challenge of occupational SB, by utilising a behaviour change approach and embedding interventions in IoT-enabled everyday objects. Two research question (RQs) were proposed in Chapter 1, which were further developed into sub-questions addressed in individual chapters

- RQ1: What intervention components can be used to reduce SB in office work, and through what theory-informed mechanisms of action?
  - RQ1.1 What theoretical models have bene considered to study and change SB?
  - RQ1.2 What factors and processes require modifications in order for the target behavior change to occur?
  - RQ1.3 What intervention components can be used to target those factors and processes?
- RQ2: Whether and how well can IoT-enabled smart objects/an IoT system deliver those intervention components and support those mechanisms of action?
  - RQ2.1 What technological features can be feasibly configured together to deliver interventions to reduce office workers' SB?
  - RQ2.2 What is going to be built and how?
  - RQ2.3 How acceptable, feasible and promising is the intervention and technology in office-based workplaces?

This chapter first summarises and synthesises the core findings that arise from the thesis studies in response to the RQs. It then steps back and weaves together the main threads of this thesis into a broader discussion of contributions in 4 key areas:

(i) An IoT-enabled theory-informed SB reduction intervention (*WorkMyWay*) and implications for future work on it

(ii) A theoretical understanding of SB change in office workers

(iii) A framework matrix for designing IoT-enabled persuasive technology for sustainable behaviour change

(iv) A reflection on methodology for developing and studying theory-informed behaviour change interventions

7.2 Summary of thesis studies and answers to research questions

Table 15 summarises individual studies conducted in this PhD research. Each study has been discussed in detail in the associated chapter. The following discusses findings related to the RQs.

RQ1: What intervention components can be used to reduce SB in office work, and through what mechanisms of action?

This RQ is addressed through the design of a behaviour change intervention guided by the Behaviour Change Wheel (BCW) (Michie et al., 2014), where the links between the theory-informed intervention components (i.e. Behaviour Change Techniques, or BCTs), and the theoretical constructs, or hypothesised mechanisms of action targeted by each BCT (or group of the BCTs) are specified explicitly (the left 3 columns in Table 16).

As a first step toward developing a theory-informed intervention, existing theoretically driven research on SB (Chapter 2) are reviewed to address <u>RQ1.1: what theoretical models have been considered to intervene with SB and to account for the mechanisms underlying SB?</u> The reviews found the following have been used in previous research: the social ecological model (Sallis et al., 2008), socio-cognitive theories (including Theory of Planned Behaviour (Ajzen, 1991), Bandura's Social Cognitive Theory (Bandura, 2004), Protection Motivation Theory (Wong et al., 2016), Self-Determination Theory (Gaston et al., 2016)), and the Dual-Process Model (DPM) (Deutsch & Strack, 2006; Hofmann et al., 2009; Strack & Deutsch, 2004). Those theories point to several common factors and processes that can be targeted in changing office workers' SB, ranging from reflective (e.g. intention, self-efficacy) to automatic motivational factors (e.g. habit, emotion), and from subjective cognitive processes (e.g. intention and habits) to external environmental affordances (e.g. access to relaxation facilities) and structural constraints (e.g. job demands).

Table 15 Summary of thesis studies

Chapter #	Chapter 2	Chapter 3	Chapter 4	Chapter 5	Chapter 6
Content	Literature review	Scoping review	Diary-probed interview	Design & development	Feasibility study
Aim	To summarise existing epidemiological literature SB (e.g. definition, measurement, biomarkers, consequences, prevalence, determinants)	To map and summarise evidence across disciplines on digital interventions to reduce office workers' SB, and to identify research gaps in utilising and innovating digital technologies for this purpose	To gauge all behavioural facets and processes that require modifications in order for office workers to take regular micro-breaks at work	To design and develop the intervention and delivery system *WorkMyWay* (to translate behavioural insights and stakeholder requirements to intervention components and technological features)	To evaluate the feasibility and acceptability of *WorkMyWay* intervention process (fidelity and quantity of delivery, mechanism of impact/promise for behaviour change, contextual factors)
Data source or data collection methods used (sample size);	Epidemiological literature	Scholarly publications (68 articles on 45 digital interventions)	Interviews (n = 20 office workers), diaries (40 participant days);	Data from the diary-probed interview study and scoping review + a stakeholder design workshop + technology audit/prototyping	Interviews, questionnaire, in-the-wild collection of sensor and interactional data (n=15 office workers)
Methodological framework	Comprehensive behaviour epidemiology	Joanna Briggs Institute's Methodology for Scoping Review	COM-B/Theoretical Domain Framework	Behaviour Change Wheel, & human-centred design (including participatory design)	MRC guidance on process evaluation
RQs addressed	RQ1.1	RQ2.1	RQ1.2	RQ1.3; RQ2.2	RQ2.3
Summary of findings	Interrupting SB with hourly break is a realistic target;	Information delivery, mediated organisational	In order for office workers to take regular breaks, we need to (i)	The resulting intervention draws on 16 BCTs (e.g. prompts	Despite technical issues, the IoT-enabled system can feasibly deliver BCTs such as

Summary of findings (Cont.)	Social ecological model, socio-cognitive theories and dual-process perspectives are all valuable approaches to addressing SB; potential determinants range from reflective to automatic motivational factors, and from subjective cognitive factors to external structural constraints.	support and social influences, digital logs and automated tailored feedback are well-researched technological designs in this field as they have mostly reached evaluation and implementation phases; more research in needed to exploit wireless connectivity and ambient and physically embedded interfaces as novel modes of delivery	provide credible information about SB to influence beliefs about consequences and intention (ii) heighten the cognitive accessibility of the health-related goal at points-of-behaviour (iii) support habit formation by directing and energizing repeated responses towards a stable cue (iv) support both prospective and retrospective memory of breaks and boost self-efficacy; (v) address social/external factors	and cues, habit formation, conserve mental resources, feedback on behaviours, action planning, commitment, goal setting, review behaviour goals, social rewards, and reward approximation). The resulting system consists of a wearable activity monitor, an LED reminder attached to a water bottle or any vessel and Android App that communicates with both devices and activates different LED patterns based on real-time classification of SB data.	action planning, conserve mental resources, prompts/cues, habit formation and potentially social support/norm and influence work break behaviours by enhancing prospective memory, goal accessibility, self-efficacy, automaticity of breaks and potentially the social environment. The novel mode of delivery is broadly acceptable and potentially feasible after fixing data connectivity issues and improving error notifications. However, there is in-definitive evidence that the mode of delivery could heighten the accessibility of goal/habitual action schema related to breaks via priming effect.

The findings resonate with a general challenge with theory-informed intervention design previously highlighted by Michie et al. (2011), that is, an overwhelming number of theories with overlapping constructs; correspondingly, there are numerous mechanisms of actions through which an intervention could work to influence behaviour (Michie et al., 2005).

Hence, a behavioural diagnosis guided by the COM-B/TDF is conducted (Chapter 4) to address RQ1.2: what factors and processes require modifications in order for the target behaviour to occur? Findings suggest interventions aimed to reduce office workers' SB can act on the following COM-B components (with theoretical constructs specified in brackets): psychological capability (e.g. knowledge, cognitive resources for memory, attention and decision processes, behavioural regulation skills such as self-monitoring and action planning), automatic motivation (e.g. prolonged sitting habit, affects or emotions associated with breaks), reflective motivation (e.g. intention, beliefs about consequences of taking breaks, self-efficacy to break up sitting throughout the day, cognitive accessibility of health-related goals at work), physical opportunity (e.g. job demands, time pressure, organizational climate), and social opportunity (e.g. social norm of prolonged sitting, interactions with colleagues).

Most of the above findings are corroborated by another qualitative COM-B analysis of office workers' SB (MacDonald et al., 2018) published after the thesis study (Huang et al., 2017), except for the following differences.

First, regarding physical opportunity, their findings suggested redesigning the office layout as an intervention strategy to influence SB, whereas our recommendation was focused on offering prompts and cues to interrupt sedentary work, which could be more portable and scalable, as justified in Chapter 2.

Second, they recommended challenging deep-rooted beliefs about productivity loss during breaks by emphasising the benefits of "mental breaks", whereas we found some office workers preferred taking breaks while continuing work-related train of thought. Hence, we suggested not enforcing "mental breaks" during physical breaks and allowing people to take breaks in an "autopilot" mode, potentially by making regular breaks habitual and therefore the default behaviour.

Third, within the dimension of psychological capability, the only barrier they identified was a lack of knowledge about the detrimental health outcomes of SB, whereas our study probed into the memory, attention and decision processes involved in initiating and maintaining a regular micro-break pattern and identified the following barriers related to limited cognitive resources. For instance, office workers found it difficult to keep track of time, to attend to physiological needs (i.e. internal cues) for breaks and to make break-related decisions, especially when they were caught up in work. It was additionally noted that a lack of retrospective memory of micro-breaks also hindered reflection on daily performance and self-monitoring of day-to-day improvement in behaviour in the long term.

In the first part of Chapter 5 (Section 5.2), the COM-B/TDF behavioural insights are systematically mapped into selection of intervention components using matrix tables from the BCW guide, which addressed RQ1.3: what intervention components can be used to target those factors and processes? The use of the BCT Taxonomy v1 (Cane et al., 2015) allows the intervention content to be described in a concise language understandable by other behaviour change specialists and to be usable in secondary research. The intervention mapping explicitly specifies the linkage between the proposed BCTs, mechanism of actions described in behavioural theory, and theoretical constructs targeted (the leftmost column 1-3 in Table 16).

The following paragraphs explain the intervention components in the resulting intervention and the potential mechanisms through which they can influence office workers' SB.

First, the BCTs of "information provision" and "credible source" are employed to influence SB intention by shaping knowledge and beliefs about consequences (Intervention Component 1). The intervention enhances beliefs about capabilities or self-efficacy for regular breaks with a group of BCTs including "feedback on behaviour", "conserve mental resources", "focus on past success" and "goal setting" (Intervention Components 2-5).

Table 16 Structured process evaluation guided by intervention mapping

Constructs/Mechanisms of action targeted (Chap.4)	BCTs (Chap. 5)	Intervention components and mode of delivery (Chap. 5)	Evaluation of implementation (Chap. 6)	Implications for future practice
Knowledge, beliefs about consequences, behavioural intention	Information about health consequences, credible source	1. App provides recommendations on healthy break intervals with explanation of scientific rationale and emphasize that the information is from credible sources	Majority did not recall the App screen with the "information".	The promise is unknown given low fidelity and exposure of the BCT. But it doesn't hurt for a human coach to point out where the info is in the App at the face-to-face sessions.
Retrospective memory, cognitive overload, behavioural regulation	Conserve mental resources, feedback on behaviours, self-monitoring	2. Use wearable trackers to automatically monitors sitting time and App provides daily feedback to enable user to self-monitor day-to-day changes in break patterns.	When the Bluetooth connection was intact, P's perceived the accuracy of break detection and tracking to be accurate and valuable, confirmed by questionnaire data that indicates increased memory of break patterns.	High promise via supporting (both retrospective and prospective) memory. Need to improve reliability of data connection; notify the user of disconnection to avoid adverse impacts; send reminders in advance to give the user a time window to act on the reminder to reduce dependency.
Belief about capabilities	Feedback on behaviours	3. App presents daily summary of and feedback on sit- break pattern.	Some did not fully discover the information; some glanced at it the next morning; some engaged with it extensively.	Display all the useful feedback on one screen without the need for user to swipe to view different metrics.
Belief about capabilities, positive/negative affect	Focus on past success	4. The App prompts the participant, at the end of each day, to look at the App feedback on break pattern and to verbally list moments s/he has managed to take timely breaks.	The instruction was not explicit enough. P's reported praising themselves and feeling good about themselves while viewing the feedback.	High promise despite low fidelity of delivery. In future work, the instruction to self-reflect on successful moments should be more explicitly given and explained by the human coach or/and the technology.
Goal (distal/proximal), beliefs about capabilities	Goal setting(behaviour), discrepancy between current behaviour and goal, review behaviour goals	5. Researcher prompts the person to set goals (e.g. "I want to limit my prolonged sitting within 3 episodes per day) in the App and to review and adjust goals from time to time.	The goal was seldom viewed or updated. Because the framing was too complex to be understood or embraced by the P's	The promise is unknown given low fidelity and usage of the BCT/feature. Future work should identify more meaningful metrics or wordings/framings of goals for SB reduction.
Intention	Commitment	6. Researcher ask the person to use an "I will" statement to affirm or reaffirm a strong commitment to change the behaviour.	The researcher is confident that this has been delivered as intended by strictly following the action planning protocol	High promise as proved extensively in previous research, but not specifically evaluated in this research.

Rewards (distal/proximal), goal (distal/proximal) reinforcement, positive affect	Social incentive, social rewards, reward approximation	7. The researcher informs the person that the App will congratulate him/her for achieving any reduction in prolonged sitting; reward is delivered by the App.	Some were really incentivised by the badges and congratulations, whereas others thought the badges did not make sense because of a logic error. Unexpectedly, the colour-coded timeline and pie chart work as powerful reinforcers and punishments for most P's	Use of colours with pre-existing associations could help. Formats and aesthetics of reward presentation, gamification, and credibility of the reward rule matter a lot. Their design needs to be informed by research with end users and pre-tested in prototypes in future research. Also important to consider individual differences and personalisation.
Breaking habit, self-efficacy, implementation intention (goal accessibility)	Action Planning	8. Researcher suggests the person plan taking breaks by specifying the frequency, duration and context, including developing "if-then" rules.	The researcher is confident that this has been delivered as intended by strictly following the action planning protocol (Appendix); questionnaire indicates increased break automaticity	High promise to break the prolonged sitting habit and form new habit, both based on the study and the literature. Can be supported by object-based prompts/cues.
Prospective memory, cognitive overload/, *goal priming, contingencies, resources	Conserve mental resources, prompts/ cues, add objects to environment	9. Add objects that facilitate the performance of breaks to the environment; use the object simultaneously to cue the prospective memory task naturally associated with the object (e.g. cup-cued tea breaks)	Unreliable data connection and delivery of object-based prompts/cues made P's revert to the on-screen real-time visualisation. Questionnaire data show decreased difficulty with remembering to take breaks.	Despite low fidelity of delivery, based on theory and empirical evidence, these BCTs can be promising and worth re-evaluation using a redeveloped system where the reliability and visibility of prompts is improved.
Habits, contingencies	Habit formation	10. Researcher trains the participant to develop new responses to the introduced stimuli through repetitions.	P's reported trying to follow although it was constrained by the context (e.g. in meeting); increased automaticity indicated by questionnaire but not by interviews.	High promise for change but inevitably medium fidelity of delivery because of practical constraints. Technology can be improved to incorporate more data sources, detect contexts and deliver prompts only when it is possible to act on them.
Social support, group conformity, organisational culture/climate	Social support (practical and general)	#11. P's could form teams and foster peer support to promote engagement with the intervention (not intentionally incorporated as part of the intervention)	As a contextual factor, P's joined the study together with officemates were more motivated and able to engage with the intervention and troubleshoot the system.	Despite it being unintended, group participation shows great promise to enable change via peer supports, group conformity and shaping the culture. Can be encouraged explicitly in future.
Social comparison, group norm, modelling, social support, negative affect	Demonstration of the behaviour, social comparison, information about other's approval	#12. P's could see other's sitting patterns and share strategies (not implemented in WorkMyWay technology, but could happen spontaneously and voluntarily between P's offline)	Some P's shared data with each other and reminded each other of the light on the object. Conversations between co-workers (including non-participants) about SB were triggered by the technology, which changed subjective norms of the behaviour.	Despite it being unintended, comparison, sharing of individual data and opinions on the issue triggered by the technology have promise to influence intention via shaping subjective norms. But those elements need to be designed and delivered with cautions to not introduce surveillance or other misinterpretation.

All the above BCTs presumably work on the pre-intentional stage, whereas the following BCTs are leading into the post-intentional stage, which will be further elaborated in section 7.4.2 and section 7.4.3. First, the BCT of "action planning" bridges the gap between one's intention and the in-situ behaviour and enhances goal accessibility by guiding the individual to develop and mentally rehearse "if-then" rules (i.e. forming implementation intentions) (Intervention Components 8). Second, the motivation for repeated goal-directed behaviour the situation comes from various elements: the BCT of "goal setting" can be combined with "commitment", "review behaviour goals", "discrepancy between current behaviour and goal", "social incentives", "social rewards" and "reward approximation" to increase the proximal reward associated with maintaining a regular break pattern (Intervention Components 5-7). The above work together to support the BCT of "habit formation" to establish new habit in place of the old one (Intervention Component 10) (more explanations in Section 7.4.2). The BCT of "prompts/cues", "conserve mental resources" and "add objects to the environment" can be used to partly offload the cognitive demands of the prospective memory task at the pre-habit stage (Intervention Components 9) (more details in Section 7.4.3).

Finally, although not delivered purposefully as intervention components in this research, the BCTs of "social support (practical and general)", "social comparison", "information about others' approval", and "demonstration of the behaviour" are supposed to influence SB in several ways, for instance, by changing the subjective norm of the behaviour, alleviating negative affect (e.g. guilt, stress) associated with taking breaks and gradually shaping the organisational climate.

RQ2: Whether and how well can IoT-enabled smart objects deliver those intervention components and support those mechanisms of action?

While RQ1 is concerned with what BCTs are suggested by theories and evidence as potentially effective to target SB in office workers (i.e. the intervention content), RQ2 pertains to whether and how well those BCTs can be feasibly and suitably delivered with IoT-enabled technology such as smart objects (i.e. the mode of delivery).

There is a consensus within the community of behaviour change research that the mode of delivery is a distinct aspect of intervention that should be reported separately from the intervention content (e.g. BCTs) (Carey et al., 2017; Michie et al., 2014). It is also important to consider the full range of possible modes of delivery in intervention design (Michie 2014). However, by the time of finishing this PhD and writing up the thesis, a research project led by Carey et al. (2017) on developing a clear, reliable and usable taxonomy for describing the mode of delivery for behaviour change intervention is yet to be completed and published.

Hence, a sub-question (RQ2.1) needs to be addressed to answer RQ: <u>what technological features can be feasibly configured together to deliver interventions to reduce office workers' SB?</u> In Chapter 3, the author first reviews and adapts several frameworks on persuasive technology or technological instantiations of a digital behaviour change interventions (DBCIs) (Fogg, 1998; Mohr et al., 2014; Webb et al., 2010) to propose a technology coding scheme for DBCIs targeting workplace SB, which encompass the following 7 technological features: information delivery (ID), digital logs (DL), passive data collection (PDC), connected device (CD), scheduled prompts (SP), automated tailored feedback (ATF), and mediated organisational support and social influences (MOSSI). They can be used to code various technological configurations (i.e. combined applications of the technological features) used in digital SB interventions and potentially other DBCIs.

By applying the scheme to code the 45 included digital SB interventions that targeted office workers, the review has mapped out the technological landscape and research activities in this field. It is found that the integration of "information delivery" and "mediated organisational support and social influences" (coded as "ID & MOSSI"), and that of "digital log" and "automated tailored feedback"(coded as "DL & ATF") are well-established as most research has reached the evaluation and implementation phases. Further research is warranted on interventions with more complex technological configurations enabled by IoT technologies. For instance, research on interventions that integrate "passive data connection" with "automated tailored feedback" and "scheduled prompts" and that involve "connected devices" as data sources or novel interfaces (coded as "PDC & ATF & CD" and "PDC & SP & CD" respectively) is still in its infancy. Several development and feasibility studies are identified in those configuration categories. They have demonstrated the technical feasibility, usability and acceptability of some novel mode for delivery, such as programmable everyday objects (e.g. sculptures, plastic plants, lights) that changed shape or colour as an ambient reminder for user to take breaks

(Ferreira et al., 2014; Fortmann et al., 2013; Haller et al., 2013; Jafarinaimi et al., 2005; Mateevitsi et al., 2014).

Chapter 5 answers RQ2.2 (whether IoT-enabled smart objects can deliver those intervention components) by deciding on what is going to be built and how it is going to be built. Theory-informed requirements, user requirements, technical requirements and research requirements are combined and translated into design of the *WorkMyWay* system to deliver the intervention components. According to the scheme developed in Chapter 3, the technological configuration of the *WorkMyWay* system can be coded as "ID & PDC & ATF & SP & CD", which means it integrates all of the technological features except for MOSSI. The system includes 3 hardware units that are synchronised via Bluetooth connections and delivering a number of BCTs: a wearable activity monitor that automatically tracks the user's sitting time (BCT: conserve mental resources), a smart water bottle or cup that delivers prompts and cues for interrupting SB with breaks based on real-time sedentary time (BCTs: prompts/cues, add objects to the environment, conserve mental resources, action planning, habit formation), and a multimedia interface that provides more detailed feedback on sitting patterns and support the development of a range of behavioural regulation skills (BCTs: feedback on behaviours, focus on past success, goal setting (behaviour), discrepancy between current behaviour and goal, review behaviour goals, social incentives, social rewards, reward approximation, action planning). Some of those BCTs are delivered in conjunction with a human coach (i.e. the author) via face-to-face interactions and email reminders.

The feasibility study in Chapter 6 assesses, mostly qualitatively and exploratorily, how well *WorkMyWay* can deliver BCTs and support those mechanisms of action (RQ2.3). The intervention description and mapping (The leftmost column 1-3 in Table 16) serve as the basis to structure the evaluation (column 4). Specifically, the quality and quantity of implementation of each BCT is assessed through reporting the participants' usage and experience of the corresponding intervention components designed to deliver the BCTs. The promise of each BCT for creating success in behaviour change is assessed through measuring psychological outcomes aligned with the targeted theoretical constructs (Buscemi et al., 2017) and through interviewing participants on their interactions with the corresponding intervention components.

In sum, the study suggests an IoT-enabled system including a digitally augmented everyday object is capable of delivering the designed intervention components. However, a number of technical and design issues need to be fixed in order for the system to fully deliver the BCTs as intended (i.e. higher quality and fidelity) and for all the BCTs to reach the participants (i.e. higher exposure and dosage). Those issues are summarised as implications in Column 5 of Table 16.

Despite compromised delivery, the IoT-enabled intervention shows high potential to support several mechanisms underlying SB reduction. This is evidenced by (i.) post-intervention improvements in several psychological measures (e.g. prospective memory, retrospective memory, and strength of habit or automaticity of breaks) that supposedly mediate SB reduction, and (ii.) participants' quotes that indicate high perceived value of the system in supporting memory, motivation and habit, as well as in shaping the social environment, the latter of which was anticipated but unintended by the researcher. In addition, analyses at an individual level reveals a trend of decrease in prolonged SB in 8 participants (statistically significant in 2), and increase in 5 participants (statistically significant in 1). Though longer-term studies with a larger sample size is needed to determine the intervention effect on behavioural outcomes.

As for the smart objects, they seem to be suitable for delivering or supporting the delivery of BCTs like "action planning", "conserve mental resources", "prompts/cues", "add objects to the environment", "habit formation", and potentially "social comparison/support/norm". The mechanisms of action they support include enhanced prospective memory, heightened in-situ cognitive accessibility of goal and goal-directed behaviour, self-efficacy, automaticity, and potentially changes to the social environment.

When the data connection was intact, participants perceived the technology to be accurate in tracking and recording their sitting time and breaks; they were motivated by the colour-coded feedback in the App and appreciated the additional memory aids provided by the LED prompts attached to vessels. Though participants expressed mixed views with respect to attaching the LED prompts/cues to objects, especially because of the frequent connection problems and burdensome troubleshooting. As for the extra benefit from using everyday objects to prime goals (e.g. tea break) associated with the object's function (e.g. drink), participants could not discern any effect, which was expected, because a defining feature of "priming" techniques is that the individual being primed should be unaware of the effects of priming. "Priming" is currently not yet included in the BCT taxonomy (Cane et al., 2015) despite the fact that it is widely established in cognitive psychology experiments; hence, it will be discussed speculatively in Section 7.4.3.1.

7.3 Implications for future work on *WorkMyWay*

The first contribution made in this doctoral research is the *WorkMyWay* intervention, which is grounded in theory and evidence, developed following a systematic approach, balanced with users' and stakeholder's preferences and demonstrated to be feasible.

To the knowledge of the author, *WorkMyWay* is one of the first SB reduction interventions developed using the BCW guide. Another intervention called *Stand More At Work* (*SMArt Work*) was recently developed by a group of researchers in Leicestershire, UK, also following the BCW guide and in consultations with stakeholders (Munir et al., 2018). Both interventions feature similar BCTs such as information about health consequences, prompts/cues, self-monitoring, goal setting, action planning, feedback on behaviours, but with a slightly different mode of delivery. First, for the BCTs of self-monitoring and prompts/cues, the *SMArt Work* intervention uses the Darma cushion together with height-adjustable workstations as the mode of delivery, which are less portable than the wristband and vessel accessory used in *WorkMyWay*. Second, *SMArt Work* is designed to deliver the other BCTs with a group seminar and 4 face-to-face individual coaching sessions, whereas *WorkMyWay* delivers most of them via the technological feature of "automated tailored feedback" with limited in-person support for behaviour change (i.e. only 1 session of motivational interview and 1 follow-up email). This is because *WorkMyWay* is positioned as a potentially scalable consumer product that office workers can acquire and use for their own interest, with little one-to-one support in the future. This has pros and cons. For the pro, the technology-based mode of delivery is capable of recording user interactions with and responses to different intervention components (e.g. frequency and time of using each function, latency in responding to prompts etc.), which allows implementation issues to be considered in relation to the fidelity of BCT delivery in feasibility studies and causal pathways to be modelled in future larger-scale evaluation. The con is that the technological mode limits the delivery of BCTs like social support, social comparison, modelling and identification of self as role model that are explicitly delivered with group sessions in *SMArt Work* to target the domains of social influences and social/professional identify. Nonetheless, the social influences can still occur as unanticipated pathways of *WorkMyWay*, as shown in the feasibility study, due to the fact that the technology-augmented physical objects are visible to other people sharing the physical space.

In terms of study design and strength of evidence, findings from this small yet well-designed process evaluation (Chapter 6) of *WorkMyWay* indicate that *WorkMyWay* is a broadly acceptable, highly promising and potentially feasible intervention delivery system, given that the technological issues can be fixed. It can be integrated into the everyday work practice of office workers to support their pursuits of regular break patterns. The *SMArt Work*, has been evaluated in a cluster randomised controlled trial (RCT) (n=146 participants) intervention and proved effective in reducing sitting by 83.28 minutes per workday relative to the control at 12 months and producing a number of other positive outcomes (job performance, psychological health) (Edwardson et al., 2018). This essentially lends support to the promise of the same BCTs (e.g. prompts/cues, self-monitoring, goal setting, action planning, feedback on behaviours) used in *WorkMyWay* for producing SB reduction, although the mode and fidelity of delivery can also influence the effectiveness (Carey et al., 2017). Last but not least, an advantage of the *WorkMyWay* study compared with the *SMArt Work* study was the use of the intervention mapping table as the basis for process evaluation, which allowed the mechanisms of action underlying each intervention component to be explored and scrutinised. Direct implications for future improvements and investigations of individual components have been presented in the last column in Table 16.

Before moving to recommendations for future work on *WorkMyWay*, several limitations should be noted.

First, the intervention did not sufficiently target the knowledge and intention to breaking up SB, even though they were suggested as important determinants (Chapter 4). Instead, the author placed more focus on the constructs less explored in previous research (e.g. habit, goal accessibility, memory). The studies undertaken in this thesis used self-selection sampling and filtered out those lacking the intention or concern about the issue in the first place, which limited the generalisability of the findings.

Second, the demographics of the study sample in the feasibility study was also very different from that of the general population – only 30% of the study participants were overweight or obese, compared with 61% of general adult population in England (Conolly & Saunders, 2017); 100% of the participants had obtained higher education qualifications, compared with 42% of the UK working population (Higher Education Statistics Agency, 2018). The demographics of this sample pointed to the possibility of better health-related knowledge and compliance to healthy lifestyle advice than the average population as indicated in previous research (Ross & Wu, 2006).

In addition, recruited from higher-education workplace settings, the participants were very supportive of research and tolerant of technological issues, which might not be the case for average office workers employed by other organisations with very different priorities on their agendas (e.g. financial profit). While readily accessible technical support from the researcher facilitated the research process, the rapport built over frequent contacts also made the participants' responses more susceptible to social desirability bias, illustrated by the following quote:

> *"I understand that working in a research-related world and research active school, I've got to understand that you've got the way that research works, to go through those mechanisms to make your research worthwhile and actually useful. So I don't have a problem with it." - P6 in the feasibility study*

Third, the author has intentionally decided to employ a single-group before-and-after study design, both for practical reasons (e.g. limited time and devices) and with methodological considerations. There has been a push towards a distinction between feasibility and pilot studies in the second phase of intervention research under the MRC framework (Orsmond & Cohn, 2015). Feasibility studies, such as the one reported in Chapter 6, can employ more flexible methodology and include only preliminary examinations of how participants use and respond to interventions, unlike pilot studies that typically include a more rigorous and controlled design to evaluate effectiveness. This is because a researcher striving to do too much in a feasibility study may risk erroneously judging an intervention to be unfeasible or unpromising based on underpowered significance testing (Tickle-Degnen, 2013). Furthermore, feasibility studies are iterative and adaptive in nature, which means necessary adaptions to intervention and research processes in vivo are allowed (e.g. the break detection threshold adjustments mentioned in Chapter 5 and user interface tweaks documented in Chapter 6 both happened during the feasibility study) and should be prioritised even if they preclude preliminary efficacy analysis (Orsmond & Cohn, 2015). The sample size was small, albeit comparable to similar feasibility studies in this field (Boulard Masson et al., 2016; Cooley et al., 2014; Mackenzie et al., 2015; Pedersen et al., 2014) and sufficient to address the study aims (i.e. feasibility and acceptability). Nonetheless, a later study with an appropriate design (e.g. RCT) and sample size is necessary for efficacy evaluation.

Finally, although the explicit mapping helps clarify causal assumptions and potentially identify weak mechanisms of action underlying specific BCTs, the primarily qualitative uncontrolled study design was not conducive to validating the underlying theoretical underpinnings. Future studies can employ factorial (Collins, Murphy, & Strecher, 2007) and "n-of-1" single-case designs (Hekler et al., 2016) to test the effect of individual components on behaviour. Evidence can also be complemented with laboratory studies that investigate the underlying cognitive effect of specific BCTs or mode of delivery, for instance, the effects of object-based versus gadget-based cues on activation and unconscious pursuit of goal-directed break actions, using experimental paradigms for measuring implicit cognitions (for a review, see (Nosek et al., 2011); for a more detailed speculative discussion on the potential priming effect, see Section 7.4.3.1). The intervention mapping table in this thesis can be used as a roadmap to link psychological constructs/underpinnings to specific technological features and BCTs.

7.3.1 Recommendations for future work on WorkMyWay

The studies undertaken in this thesis were situated in the development and feasibility/piloting phase under the UK medical research council (MRC) framework (Figure 39) for developing and evaluating complex interventions (Campbell et al., 2000; Craig et al., 2008, 2019).

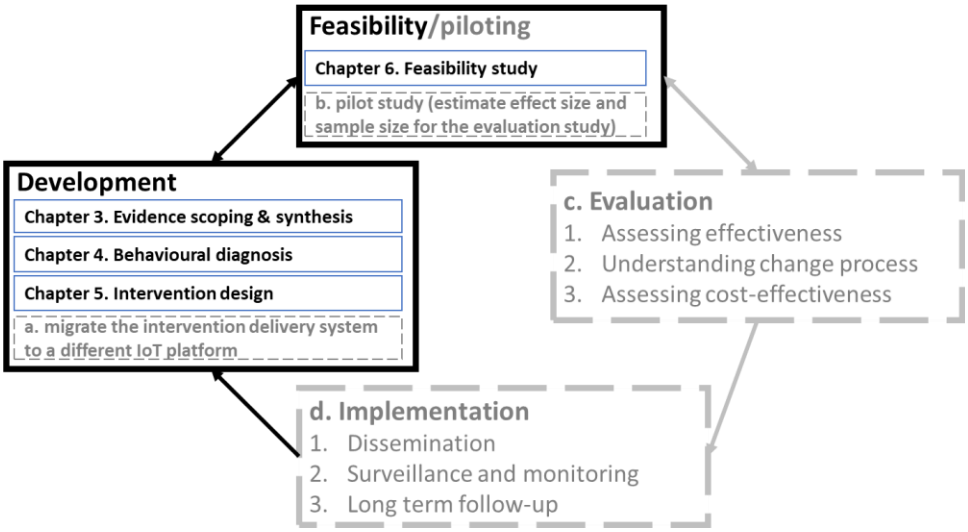


Figure 39 The thesis studies and anticipated work under the MRC framework on complex intervention development and evaluation (Craig 2019)

The grey fonts in Figure 39 list the anticipated development and studies beyond this thesis as per the MRC framework, which include:

1. Engineering and development work to improve the technology and especially fixing the data connection and synchronisation problems, potentially by migrating the whole system to a different App using a different IoT hardware and API rather than the *MetaWear*;
2. A pilot study with a more rigorous design (e.g. pilot RCTs), focused on piloting and validating outcome measures, estimating effect size to inform a formal larger-scale trial in the evaluation phase. The following research questions need to be addressed:
    a. If the technology works well and delivers the BCTs with high fidelity, will office workers adhere to it and integrate it into everyday routine in the longer-term?
    b. Is the intervention effective in reducing prolonged and total SB? Does the effect wear off (i.e. is it novelty effect)?
    c. Will office workers continue the new break habit or relapse to the old behaviour if the technology is removed (i.e. is there dependency on the technology reminders)?
3. More design work (public and patient involvement (PPI)/requirement elicitation) that engages more representative samples of office workers and stakeholders from

a more diverse range of organisations (e.g. private sector), to investigate the following research questions:

a. How could organisations facilitate the delivery of *WorkMyWay*, given initial evidence suggesting its feasibility and promise to support individual change? Is there a potential to create organisational change?
b. Would employees trust and use *WorkMyWay* more, if it is promoted and endorsed by the management, or less (e.g. due to fear of surveillance)?
c. How to reach and engage office workers who are most sedentary yet unmotivated to change SB?

7.4 Implications for theoretical understanding of sedentary behaviour change in office workers

The second contribution made in this doctoral research is providing inspirations for theoretical research on SB change. This is done by developing a theory-informed behaviour change intervention and exploring how different theory-informed intervention components work in the wild. The use of the BCW (including COM-B/TDF) to guide behavioural diagnosis (Chapter 4), intervention design (Chapter 5) and evaluation (Chapter 6) enables a comprehensive inquiry into theoretical constructs. Moreover, the explicit links between outcomes from different steps allow weak causal links originating from the theory to be identified, discussed and refined to reflect contextual factors in real-life settings. However, the primarily qualitative approach determines that the theoretical contribution of this research is more about generating rather than testing hypotheses.

The following sub-sections summarise the hypothesised mechanisms of action that could underlie SB change in office workers illuminated by this research, which offer directions for further research on proving the effectiveness of the theory-informed BCTs and validating the underlying mechanism.

7.4.1 Enhancing self-efficacy for taking regular micro-breaks

As reviewed in Chapter 2, self-efficacy, or perceived behavioural control, is a well-established socio-cognitive construct underlying SB (Hadgraft et al., 2017). Bandura's Social Cognitive Theory (SCT) suggests that self-efficacy beliefs shape the outcome people expect their efforts to produce and in turn shape how much effort people will input over the course of pursuing behaviour change (Bandura, 2004).

Self-efficacy can be enhanced via mastery experience, vicarious learning, verbal persuasion, goal setting and social support (Bandura, 1986, 2005). The thesis findings add to the literature that, in the context of SB reduction, the mere feedback on past micro-breaks might be powerful enough to shape people's beliefs about their capabilities to break up SB at work. This is because compared with other health-related behaviours (e.g. exercise and diet), SB is even more unstructured, pervasive and accumulated throughout the day, which makes it difficult to self-monitor SB and self-assess the degree of sedentarism on different days. The workplace context adds to the difficulty, because most cognitive resources are allocated to the main working task, leaving little spare resources for remembering sitting time or break frequency. However, the perception (or misconception) that oneself has not moved at all throughout the day can be depressive, as reported by participants. Fortunately, the belief about capability can be altered by providing accurate feedback.

In addition, self-monitoring tools that complement human retrospective memory, such as the paper diary used in the behavioural diagnosis (Chapter 4) and the technology-based activity monitors used in the feasibility study (Chapter 6) can be both of value. Compared with paper diary, the technology-based monitor has the extra advantage of acquiring more fine-grained measurement of physical activity and picking up micro-breaks, which has shaped participants' perceptions of what count as breaks, and in turn enhance self-efficacy for regular breaks.

In the debriefing interviews, participants reported the tracking and feedback function of *WorkMyWay* was highly accurate and informative, as long as the data was recorded well. This was confirmed by the significant difference in pre- and post-intervention measurement of retrospective memory of sitting and breaks (t=7.926, p<.001). However, it should be noted that the items used for measuring retrospective memory had not been previously validated. The author made the decision to make the post-intervention questionnaire items slightly differ from the pre-intervention in that it incorporated the monitoring of *WorkMyWay* as part of the "ability to remember" (e.g. *"Provided that WorkMyWay functions properly, at the end of each day, I have an idea of how much time I've spent in prolonged sitting/how often I have taken breaks"*). This meant the data only provided the evidence that the intervention aided, or extended, rather than improved participants' memory capacity (more discussion on implications for technology design in Section 7.5).

The increase in the questionnaire item on perceived behavioural control of breaks was not statistically significant (t=.487, p=.634). This could be because the construct was assessed with a single item adapted from an unvalidated questionnaire used in a previous study on occupational sitting (De Cocker et al., 2014). Hence, the measurement might not be sensitive enough to capture change. Another explanation was that the temperamental functioning of *WorkMyWay* compromised its positive influence on overall self-efficacy, despite the promise indicated by interview quotes.

A better understanding of the behaviour and the likely process of change can inform intervention designers and policymakers in designing effective intervention strategies (Craig et al., 2019). The findings from this thesis suggest that supporting self-monitoring and retrospective memory of micro-breaks has the potential to encourage regular break behaviours to reduce SB in office workers via constructs of self-efficacy (aka. perceived behavioural control, beliefs about capabilities). Hence, a design goal for future SB interventions is to provide reliable and meaningful feedback on, not only the total amount of sedentary time, but also the patterns in which it is accumulated. IoT technology can be of value in terms of providing continuous behavioural sensing and fine-grained feedback to complement human memory, promote self-reflection and support self-efficacy.

7.4.2 Developing a habit of breaking up sitting regularly throughout workdays

The literature review in Chapter 2 has highlighted that the stable physical environment and routinised nature of office work makes office-based workplace particularly conducive to the formation of habitual responses (Gardner et al., 2017). In fact, many interventions fail to create sustainable behaviour change because existing "bad" habits are unchanged, or the new "good" behaviours are not developed into habits yet (Wood & Rünger, 2016). There is a lack of understanding on how an automatic motivation to break up sitting regularly can be fostered with interventions in the workplace. This research is among the first attempts to address this knowledge gap.

Chapter 2 has reviewed the dual-process model (DPM) and its neuroscientific and cognitive experimental evidence. Despite a rising interest in theoretical research drawing on the DPM to understand SB (Conroy & Maher, 2013; Maher & Conroy, 2016), workplace SB interventions underpinned by the DPM are non-existent. Most existing workplace SB interventions target either the Type 2 reflective process (e.g. intention, self-efficacy) through education and persuasion, or the Type 1 automatic process (e.g. habit) through environmental restructuring, or both processes but somewhat in separation (e.g. multicomponent interventions involving environmental and educational components, which do not support each other). There is a general lack of research that looks at the interface or interplay between the two systems.

The majority of habit-based SB interventions have not moved beyond providing scheduled prompts for breaks, which is underpinned by the behaviourist premise that if the stimulus-response (S-R) links are repeated frequently enough, they will become automatic and strong enough to replace the old S-R links (Cooley & Pedersen, 2013; Green et al., 2016). However, this approach has overlooked the cognitive constructs that habits rest on, such as goals, attention, associative memory, and the interplay between the automatic and controlled systems (Bargh & Ferguson, 2000; Tobias, 2009; Wood & Neal, 2007; Wood & Rünger, 2016).

It was not until recently that Pinder, Vermeulen, Cowan, & Beale (2018) proposed the Habit Alteration Model (HAM) to explain relationships between the numerous Type 1 and Type 2 constructs related to habit triggering and formation. Many points raised by Pinder and colleagues coincide with those made by the thesis author in Chapter 2. For instance, in line with the DPM reviewed in Chapter 2, the HAM suggests although habit operates in the Type 1 (automatic) system after it is formed, strategies that break old habits and form new habits often need to draw on Type 1-targeted and Type 2-targeted strategies. Indeed, the key for behaviour change interventions to support habit formation is to transfer behaviour from the slower reflective process (Type 2 system) to the faster automatic process (Type 1 system). Implementation intention, which seems to be a Type 2 strategy, facilitate habit formation by increasing cognitive accessibility of the goal and goal-directed behaviour in the situation (Webb & Sheeran, 2008). Finally, the HAM recommends Type 2 strategies (e.g. information provision, goal setting, action planning) be delivered via preparatory training sessions rather than just-in-time at points of behaviour, when the user may have very limited spare cognitive resources.

WorkMyWay was consequently developed as one of the first interventions to target both Type 1 and Type 2 systems and to support the Type 2-to-Type 1 transition. A statistically significant post-intervention increase in automaticity of micro-break behaviour measured by SRHI (Gardner et al., 2012) shows the promise of *WorkMyWay* for targeting sedentary habits in the workplace. The author is aware that the study design (i.e. before-and-after without control) prevents us from drawing a definitive conclusion on the effectiveness of the intervention; it is also unclear which of the BCTs enabled habit increase and through what causal pathways (e.g. "heightened goal accessibility" or "increased proximal reward value"), without a factorial design or implicit cognition laboratory paradigms.

In acknowledging those limitations, in what follows, the author will speculatively explain the possible mechanisms underlying the increased automaticity based on literature and interview data from the feasibility study.

First, the BCTs of "goal setting" and "commitment" helped establish a mental representation of a desired end state (i.e. a goal) (Austin & Vancouver, 1996) that directed and prepared individuals to engage in the new promoted behaviour (Veltkamp, Aarts, & Custers, 2009). At the motivational interview, the author guided participants to make statements in the form *of "I intend to reduce the amount of prolonged sitting to xx minutes per day"*, which resulted in a commitment to pursue the sitting reduction goal (Webb & Sheeran, 2008). This statement was also entered in the App for participants' own records.

Second, the BCTs of "action planning" and "prompts/cues" helped connect the goal-directed behaviour with an anticipated situation via "if-then" rules (i.e. implementation intention). Mental rehearsal of implementation intention has been suggested by the literature as an effective strategy for strengthening the cue-response associations and in heightening the cognitive accessibility of the goal, the goal-directed action and the specified cue in the situation (Adriaanse, Gollwitzer, de Ridder, de Wit, & Kroese, 2011; Hagger & Luszczynska, 2014). That partly accounted for participants' increased awareness of their sitting problems and needs for breaks during the study. It should be noted that at the beginning of the study the "if" condition in the action plan was specified as certain LED patterns, which caused negative impacts on behaviours, because of frequent technology failures. Hence the researcher changed the protocol for action planning and guided participants to form action plans based on the sitting time (i.e. an internal cue that requires self-monitoring), whereas the LEDs attached to vessels could be seen as an externally distributed representation of the completion status of the prospective memory task (more details in Section 7.5). Moreover, the interview quotes suggested that the LED seemed to activate some kind of goal-directed mental representations that drove participants to stand up sooner.

Third, the BCTs of "social reward" and "reward approximation" were used to incentivise and energise repeated responses to cues. By congratulating the user for achieving goals and completing small steps toward the goal, the intervention induced proximal rewards with a much shorter psychological distance than health-related benefits. Interestingly, the consistent use of colour for the on-screen feedback and LED light also helps to transfer motivational value from the Type 2 to Type 1 system to energise actions in the situation. Participants seemed to assign different affective valence to the green and red presented by the system, both via the App and the vessel. Participants also seemed to self-deliver the additional BCTs of "self-reward" and "remove punishment (including negative reinforcement)". It could be the reward/punishment signals emanating from the green/red colours associated with mental representations of positive/negative end states that have driven the in-situ break actions. This was evidenced by phrases like *"lovely to see the greens and yellows", "beat the reds"* used by participants to describe their experiences and motivations.

In view of the promise of the above strategies in improving automaticity of taking micro-breaks throughout the day, future habit change interventions could consider a 3-step intervention package that target 3 cognitive constructs "habit" rests on: (i.) setting up a mental representation of a desired end state (i.e. **goal**) that directs the counter-habitual action (e.g. get up regularly for health); (ii.) heightening the in-situ **cognitive accessibility of the goal** and goal-directed action, via implementation intention, point-of-behaviour prompts/cues and potentially environmental priming; (iii.) increase the **proximal reward** value associated with the goal-directed action via carefully designed feedback to energise repetitions over time.

7.4.3 Supporting prospective memory at a pre-habit stage

The construct of prospective memory (PM) emerged as an important consideration over the research process through the lens of COM-B. Only one prior study has considered the scenario of interrupting sitting regularly as PM task, and piloted the approach of extended cognition to support the performance of this PM task (Grundgeiger et al., 2017). This thesis contributes to this line of research by highlighting the commonality between

PM, habit formation and goal accessibility; it also enriches the discussion by presenting data on different ways IoT-enabled prompt/cues were appropriated by office workers to facilitate the PM task of taking regular breaks in the real life.

As Chapter 2 did not introduced this theoretical construct, which was found relevant only after the behavioural diagnosis (Chapter 4), this section will first briefly introduce the cognitive science literature on PM, then explain its relationship with habit formation, and finally discuss findings from the *WorkMyWay* study, in relation to supporting PM in the wild, including speculative discussion on potential priming effect and the issue of dependency.

PM can be conceptualised as a deferred intention to perform something at a future point. Despite the term, PM in fact is not only a memory process. Instead, a plurality of neural networks is involved in performing a PM task, in order to regulate the formation, retention and retrieval of the deferred intention, and monitor for the time window or cues for executing the intention (Cona, Scarpazza, Sartori, Moscovitch, & Bisiacchi, 2015; McDaniel & Einstein, 2000).

PM and habit are closely related. At an early stage of forming a new habit or breaking an old habit, the situation essentially constitutes a PM task. If the PM task is frequently practised as a sequence of actions, it then get "chunked" into procedural memory and consequently become habits (Gardner, Phillips, et al., 2016). A key cognitive construct shared by PM and habit is "the ease of retrieval of the deferred intention from memory" (in a PM terminology) or "accessibility of the goal and goal-directed response in the context" (in a habit terminology), which can be enhanced momentarily or permanently.

Based on the above, the early stage of habit formation can be facilitated by several strategies informed by PM research (Dismukes, 2012). First, people are generally better at performing event-based PM (executing an action on encountering of cues) than time-based (executing an action within at a future timepoint or a specified time window) PM tasks, as the former situation permits external cueing of an intended action whereas the latter requires active monitoring to identify the time to act. For instance, asking one to remember "to take a pill with every meal" is more effective than "to take a pill 3 times throughout the day" (Stawarz et al., 2017). Similarly, remembering to take a break in response to a scheduled prompt, or empty vessel, or a physiological need, is easier than remembering to take a break every hour. Second, cues that are salient and distinctive produce better PM performance, presumably because they attract attention and elicit more extensive processing. Third, cues that are highly associated with the deferred intention or well-defined are more effective in retrieving the deferred intention from memory. This suggests forming an implementation intention that explicitly specifies situations for executing the deferred intention facilitates PM performance.

The design of *WorkMyWay* mirrored the above strategies. The automated activity tracking and scheduled prompts of *WorkMyWay* essentially converted a time-based PM task to an event-based one and lowered the difficulty (McDaniel & Einstein, 2000). The LED that appeared as an odd attachment to a vessel was quite distinctive and noticeable, even if it was not lit up, and more distinctive when it was glowing or blinking. The augmented vessel itself was highly associated with the deferred intention to take water/tea breaks. Implementation intention was also used to explicitly associate the cue (be it the LED, an empty vessel, or thirst) with the action of standing up (and refilling vessels).

7.4.3.1 The potential priming effect of the smart object

In addition to the above strategies that are known to be capable of facilitating PM, the appearance of the object might also have a priming effect that enhances the cognitive accessibility of the break-related goal at an unconscious level. This is one of the five reasons the author put forward in Chapter 1 to justify the enchanted object approach. The inability to introspect one's automatic cognitive processes makes it difficult to apply and study implicit cognitive phenomenon such as priming out of laboratories. Priming is also not included in the current BCT taxonomy. Hence, rather than providing a definitive explanation of the process, the following discussion is speculative and aims to inspire future theoretical and applied research on object-based priming of goal-directed behaviours.

Participants' accounts of the response to the LED reminder suggest the effect might be, at least partly, driven by the impulsive and implicit Type 1 system (e.g. *"my first instinct would have been to remind myself, 'oh I have to get up and I have to do something'", "I found that quite difficult not to"*). It warrants a series of experiments employing implicit cognition laboratory paradigms to explore the following possibilities/questions:

(i). To what extent the augmented objects primed the goal to stand up sooner at an unconscious level in the situation? It could possibly be the participation in the study, and ongoing engagement with the interventions that heightened the overall cognitive accessibility of the break-related goal over the period of study; it could also be the glances at the technology that momentarily heightened the cognitive accessibility of the goal in the situation.

(ii). What stimulus or stimuli (the LED vs. object vs. smartphone) worked as the prime(s)? It could be merely the LED colour that activated the goal to "beat the reds", as underscored by a number of participants during the interview; or it could be the cup/water bottle that participants glanced at more regularly because of the study, which was supported by reports of increased liquid consumption during the study. If the former was the case, then it was less important what object the LED was attached to, which was suggested by 1 participant (P12), who attached the LED to her keyboard in post-study use. If the latter was the case, then it means the main function of the LED was to draw attention to the object-based cues, which leads to 2 further questions – (a) after removal of the LED, will the ordinary vessel still continue to work as a constant cue for keeping hydrated and refilling it? This calls for longer-term studies with follow-up assessments. (b). does it make a difference whether the LED reminder is designed to stand out as an odd attachment to the vessel (as in the current design), or embedded as an integral part of the vessel (as most market-ready smart products) in the first place? A comparative study is warranted answer this question.

(iii). What type of priming was it and what concepts were activated? It could be a case of subliminal priming of perceptuo-motor links (e.g. the sight of vessel triggers drinking) that happened pre-attentively, i.e. before conscious perception (Eimer & Schlaghecken, 2003; Neumann & Klotz, 1994). Or it could be supraliminal priming of a goal-directed action schema (e.g. the sight of a mug triggers the sequence of actions involved in a tea break) that required conscious perception but little conscious processing. Or it could be activating an even higher-order goal (e.g. an all green healthier work break pattern) (Aarts & Custers, 2012; Custers & Aarts, 2007). The pursuit of the higher-order goal could be partly unconscious, and energised by the affective signals (e.g. positive experience of seeing all "green" in the feedback) emanating from the colours (Aarts et al., 2008; Elliot & Maier, 2012; Mehta & Zhu, 2009), as suggested by the interviews. There could be other types of priming involved, or a combination of the above different types of priming, which offer directions for experimental research to strengthen the theoretical ground for enchanted object design.

7.4.3.2 Address the issue of dependency on the technology-based memory aids

The usefulness of the combination of strategies used in *WorkMyWay* to facilitate PM was evidenced by the significant post-intervention decrease in self-reported difficulty of the PM task of keeping track of time and remembering to take breaks. However, it should be noted that the post-intervention questionnaire items assessed the break-related PM as the ability to remember to take breaks with the help of the technology (aided-PM), similar to that of retrospective memory. This suggested while *WorkMyWay* aided participant in performing the PM, there is a risk that they depended on the memory aids, which has been noted in previous research on promoting medication adherence (Renfree, Harrison, Marshall, Stawarz, & Cox, 2016; Stawarz, Cox, & Blandford, 2014).

The issue of dependency on the LED reminder surfaced at the early stage of the feasibility study on *WorkMyWay*, where some participants sat for hours waiting to be prompted while the data was out of sync because of connection problems. However, the study also found that users could be adaptive and innovative. As the study went along, participants (as well as the researcher) developed more realistic expectations about the technology. Some developed an alternative use strategy to proactively check sitting time, although this meant they had to revert to the screens for information on the actual time. After some time, they seemed to internalise the rhythms of breaks and saw it as a goal to prevent the red colour signals from occurring, both on the LED and in the App. This had inspired the researcher (i.e. the author) to change the action planning protocol from "*I will take a break when the light is on*" to "*I will take a break…before it reaches xx minutes*". The former implied reliance on the LED reminder, whereas the latter promoted self-cuing for breaks and negative reinforcement.

This speculative interpretation was supported by ad-hoc analysis of post-intervention questionnaire data that suggested the automaticity of *"taking regular micro-breaks throughout workdays"* (mean =4.85, SD=.441) was significantly higher than that of *"taking a micro-break whenever the LED is glowing"* (mean = 3.4, SD=1.238), both based on 7-point Likert scale adapted from the validated SRHI (Gardner et al., 2012). The interview quotes further illustrated that, while participants' responses to the LED were still based on conscious decision, the overall awareness, or accessibility of "taking regular breaks" seemed to have been heightened.

Although frequent technology failures were unexpected and frustrating, the findings and user adaptations due to the failures raised interesting questions. One of the questions concerns the distribution of changes over time and between the technology, human cognition, and the physical environment, that we want to enable with DBCI designs. With hindsight, the change in the protocol during the study had essentially loaded part of the cognitive demands (i.e. monitoring for the window of opportunity for execution) back onto the user. In terms of chronological distribution, while the cognitive accessibility of goals can be momentarily enhanced by explicit memory aids (aka. reminders) (Tobias, 2009) and implicit priming techniques (Förster, Liberman, & Friedman, 2007) (possible types of priming have been discussed in Section 7.4.3.1), their effects are not long-lasting. The chronic accessibility of goal related constructs can be enhanced by frequent repetitions in a stable context (i.e. habit formation) (Tobias, 2009) and altered by cognitive strategies such as implementation intention, cognitive bias modification, self-control training (Pinder et al., 2018), which demands user efforts upfront, but reduces the dependency on technology-based memory aids in the long term.

This leads to our discussion on HCI design implications from the thesis findings.

7.5 Implications for HCI design and research

This research attempted to design for a complicated and interesting case of behaviour change, where the Type 2 reflective process (e.g. goal-directed PM performance) needs to be gradually transferred into the Type 1 automatic process (i.e. formation of a new habit) in place of an existing undesirable Type 1 process (i.e. break a bad habit). Over the design and research process, it occurs to the author that this could potentially be mapped onto the tension between foreground (i.e. occurs in the centre of attention) versus background (i.e. attentional peripheral) interactions in HCI (Buxton, 1995). The advocacy for designing background interactions probably dated back to Weiser's vision (Weiser, 1991) that technology will weave into everyday life and become unnoticed eventually, which was followed on by his call for calm computing (Weiser & Brown, 1995). As mentioned in Chapter 1, enchanted objects mirror the ethos of invisible and calm computing in many ways. On the contrary, Rogers (2006) argued that this embeddedness and calmness should be counter-balanced with the need to design UbiComp technologies that engage, stimulate and provoke people to be reflective when needed; Rogers also suggested one of the promising research areas for designing engaging UbiComp experience be persuasive computing.

Early persuasive computing (Fogg, 1998) mostly typified foreground interactions, which is also revealed by the word "persuasive". As user reactance to persuasive technologies has been noted as a big challenge (Gouveia et al., 2015), Adams, Costa, Jung, & Choudhury (2015) proposes mindless computing, as a new approach to persuasive design that taps into Type 1 influences at the background and that shapes human behaviours without being too demanding on cognitive resources, executive function or willpower. In this regard, mindless computing, seems to strike a balance between the background "invisible UbiComp" that automates tasks and the foreground "persuasive technology" that demands user attention and efforts.

However, mindless computing utilises but does not modify Type 1 processes, which gives rise to another tension - if the user is influenced to make a specific response under a manipulated condition, without the default response in the brain being altered (i.e. Type 1 change), it then requires the technology to be constantly present at points of behaviour to sustain such change, which causes dependency. Indeed, the dependency on technology and behavioural relapse after disuse has been raised as an issue for both mindful and mindless type of persuasive computing (Attig & Franke, 2018; Renfree et al., 2016).

In HCI literature, a lot of emphasis has been placed on creating products and experiences that engage users for a long time. It is assumed that well-designed technologies will, and have to be constantly penetrating peoples' lives. However, this is not necessarily the only option for persuasive design. In view of the above, the thesis author proposes to introduce the axis of "time" to this domain.

7.5.1 A framework for designing technologies for sustainable behaviour change

In what follows, the author presents a 2-dimensional matrix framework (Figure 40) for designing persuasive UbiComp for sustainable behaviour change. The framework is speculative in nature and is aimed to organize the author's thinking resulting from the

PhD project in relation to numerous existing UbiComp design concepts and frameworks.

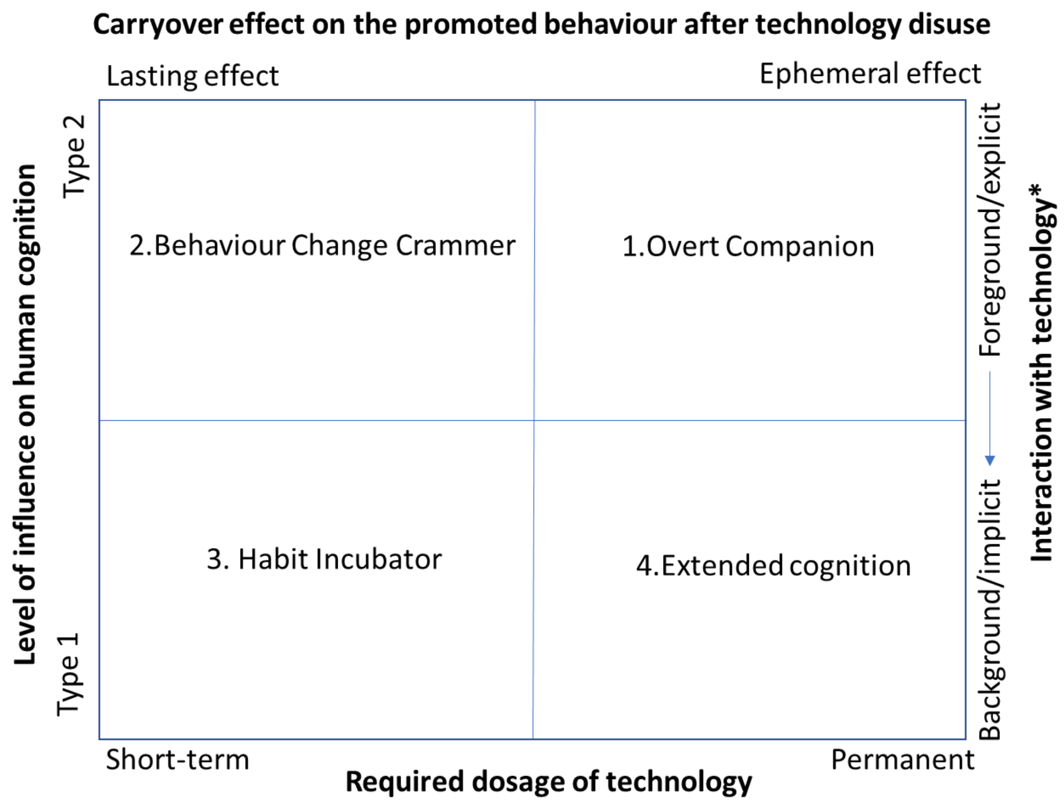


Figure 40 A framework for designing persuasive UbiComp for sustainable behaviour change ("Sustainable Change Framework")

The vertical axis of the framework categories DBCIs (or the DBCI components, the same below) based on whether they influence behaviours via Type 1 or Type 2 system. It should be noted that users of Type 1 DBCIs are not necessarily unaware of their encountering with the technology; they are just unaware of the mechanisms of impacts (Pinder et al., 2018), and in some case also unable to control the process of change.

With the horizontal axis, the framework encourages designers to think about the "dosage", or duration of technology intervention required for maintaining the target behaviour, and whether the effect of their technology on the behaviour continues or vanishes after disuse of the technology.

Therefore 4 quadrants (Q) emerge, representing 4 roles that can be played by technology in endeavours to create sustainable behaviour change:

Q1: Overt Companions: they are technologies that explicitly promote desirable behaviour at a conscious level by providing continual monitoring, reminders, feedback and motivational multimedia contents in the long term; as their influences on behaviour ceases after the user stops using them, ongoing usage and engagement is therefore required to sustain behaviour change. Examples include the scheduled break reminder feature implemented in smartphone Apps or computer software, pedometers or the summative feedback feature in other quantified-self type of devices and Apps.

Q2: Behaviour Change Crammers: they tend to be intensive behaviour change intervention packages and programmes that target knowledge, coping strategies, beliefs about consequences, self-efficacy, social norms, social environment and/or intrinsic motivation underlying the focal behaviour. As those theory-informed mechanisms of action are targeted, the behaviour change effects are long-lasting, which is evidenced in studies with long-term follow-ups (e.g. (Healy et al., 2016)). Behaviour Change Crammers typically feature elements such as theory-informed online-delivered persuasive materials, motivational interviews, coaching sessions, and exercise programmes with team champions etc. that focus on improving reflective motivation and skills.

Q3: Habit incubators: like the previous quadrant, Habit Incubators are intensive technology-delivered training/coaching sessions; but unlike Crammers, they aim to change the default behaviour, attentional biases, chronic goal accessibility and associative memories in Type 1 system, which include but are not limited to habits. Hence, the term "habit incubators" is used to broadly refer to deigns that change the default automatic response in an given context. Examples of Habit Incubators include cognitive bias modifications (Pinder, Fleck, Díaz, Beale, & Hendley, 2016), guided action planning (e.g. implementation intention) (Pinder, 2016; Wicaksono & Beale, 2019) to support habit formation, and the training elements in technology-delivered therapies for depression, anxiety and various other psychological disorders (Andrews, Cuijpers, Craske, McEvoy, & Titov, 2010; Carlbring, Ekselius, & Andersson, 2003).

Q4: Extended cognition: they can also be called secret determinants or persistent nudge, and mostly involve altering aspects of the environmental context to influence behaviours via Type 1 processes, without changing the original context-response contingencies; the presence of the technology or the new context is therefore required to sustain the target behaviour. These include technology-delivered supraliminal and subliminal priming (Pinder, Vermeulen, Cowan, Beale, & Hendley, 2017), manipulation of perceptions (the frequency-altered feedback and mindless plate in (Adam et al. 2015)), and many examples under the umbrella of "nudge" and choice architecture reengineering (Thaler & Sunstein, 2008), colour priming and embodied cognition (Broeders, Lakens, Midden, & Ham, 2008; Lu, Ham, & Midden, 2015; Maan, Merkus, Ham, & Midden, 2011).

7.5.2 Mapping UbiComp concepts to the Sustainable Change Framework

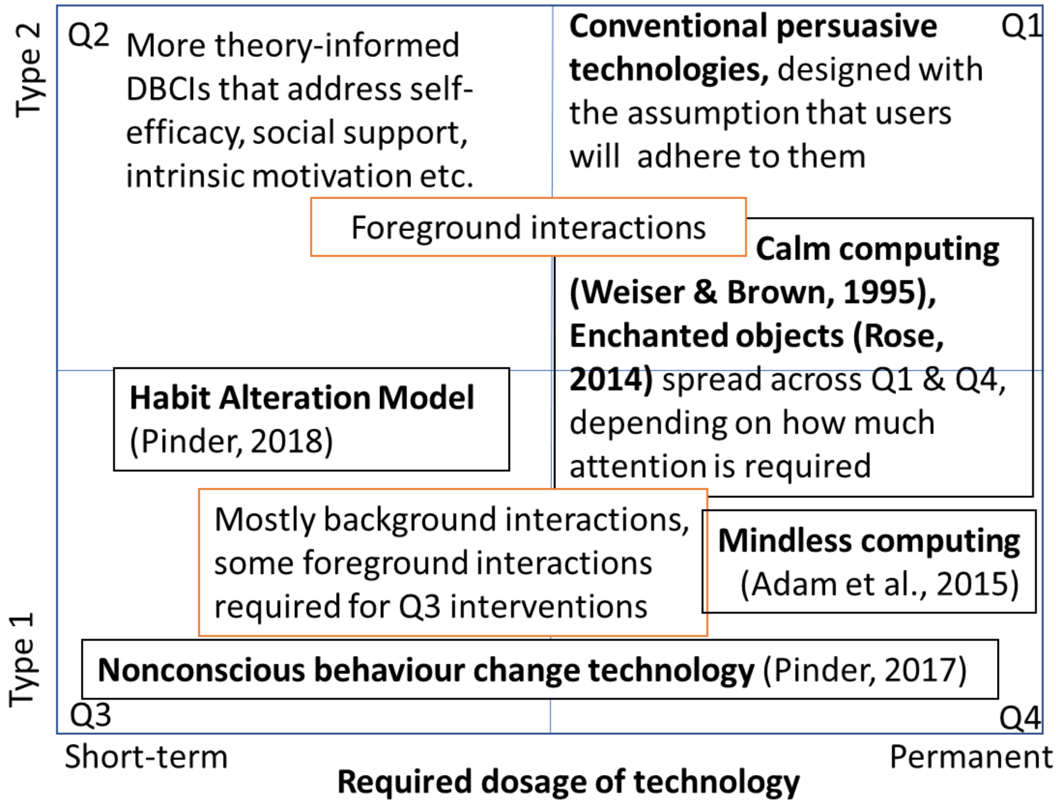


Figure 41 Mapping existing UbiComp frameworks/visions onto the "Sustainable Change Framework"

In this sub-section, the author will attempt to map some of the UbiComp design visions and frameworks on to this framework.

First, "nonconscious behaviour change technology", a term coined by Pinder (2017) to refer to interventions that target automatic cognitive processes for behaviour change, falls into the bottom half of the matrix. The example of subliminal priming App (Pinder et al., 2017) goes into Q4, and the design probe delivering guidance on implementation intention (Pinder, 2016) and the Cognitive Bias Modification intervention App (Pinder,

2017) belong to Q3. Mindless computing (Adams et al., 2015), which sits in Q4, is a subset of nonconscious behaviour change technology that utilises, but does not change, the unconscious process.

Type 1 versus Type 2 distinction is related to, but different from, the implicit versus explicit, background versus foreground interaction distinction in HCI (Buxton, 1995; Ju & Leifer, 2008). The meaning of "implicit" in the psychology literature also differs from that in the HCI literature, with the former referring to unconscious automatic psychological processes and the latter to interactions occurring in the periphery of attention based on tacit knowledge. Type 2 technologies (Q1, Q2) exclusively require explicit interactions; the majority of Type 1 technologies (Q3, Q4) require only implicit, background interactions, with the exception that some Q3 technologies also require foreground interactions and user's conscious attention, such as dialogue supports that guide users to form implementation intention, and Apps delivering cognitive bias modification trainings (Pinder, 2017). Calm computing (Weiser & Brown, 1995) supposedly moves between the centre and periphery of conscious awareness; however, it is usually unspecified in the literature whether the technology influences behaviour via Type 1 or Type 2 mechanisms. Similarly, although Rose argues enchanted objects should draw on the fast Type 1 cognitive process, most of the design examples (e.g. the Ambient Orb) in his book seems to fall into Q1 rather than Q4.

The horizontal axis of the "sustainable change framework" essentially gets to the core about the distribution of change between the external world and the user. Traditionally, the discipline of behaviour change tends to focus on developing the capabilities and motivations of the human, whereas an HCI or cognitive system engineer may argue that, if the key is to help people perform the task successfully, it is less important which specific agent remembers or even performs the task (Grundgeiger, Sanderson, & Key Dismukes, 2014). This is reflected in Figure 41 where the majority of HCI design concepts fall on the right and most DBCIs coming from behavioural medicine fall on the left. This relates to an everlasting enquiry – where to draw the line between developing knowledge in the world versus knowledge in the head (Norman, 1988). There is no right or wrong answer. Even the boundary between the two schools of thought or disciplines are more blurred nowadays, as behaviour change intervention development frameworks like the BCW have incorporated environmental restructuring and enablement as intervention functions (i.e.

moving to the right side). Nonetheless, this axis is still useful to encourage designers to think whether all technologies have to be persistently penetrating, engaging, and functioning with satisfactory reliability and intelligence in the user's life (right side), or we can design technology that self-destruct or repurpose itself after providing the initial scaffold for behaviour change (left side).

7.5.3 Analysing WorkMyWay with the framework

The author was inspired by Rose's concept of enchanted objects (Chapter 1), but expanded on it and linked it to the HCI literature on "screen guilts" (Skatova et al., 2016) and embodied facilitation of actions by technology (Hornecker & Buur, 2006), and the cognitive psychology literature on dual process model, habit formation, and goal priming (Chapter 2). The *WorkMyWay* was consequently developed and evaluated in the wild with the ambition to explore potential influences on both the automatic and reflective systems.

Different components of *WorkMyWay* can be mapped on the "Sustainable Change Framework" (Figure 42).

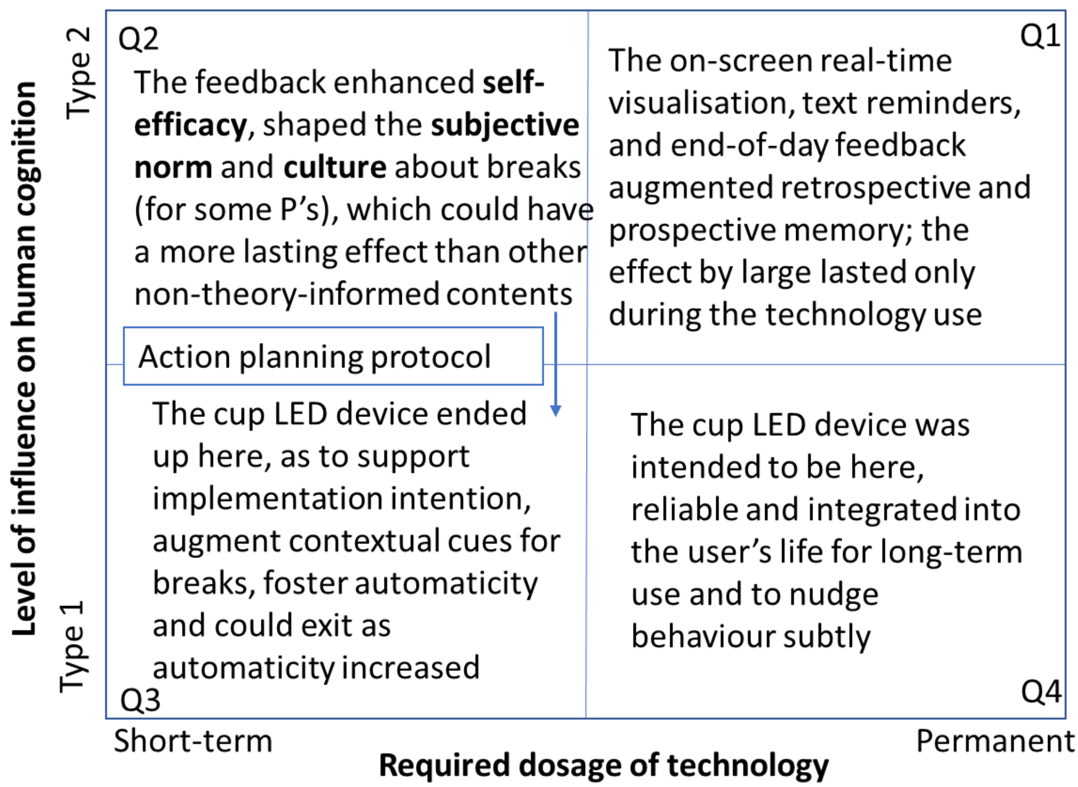


Figure 42 Mapping different *WorkMyWay* components to the "Sustainable Change Framework"

First, if we look along the vertical axis, findings presented in Chapter 6 no doubt lent support to the promise of *WorkMyWay* as an effective memory aids and an intriguing reflective tool that augmented the prospective and retrospective memory of breaks, enhanced self-efficacy and shaped social environment (upper half of the matrix). Nonetheless, *WorkMyWay* could have also worked beyond reflective processes and involve Type 1 automatic processes (bottom half of the matrix). The initial idea was to enable two parallel Type 1 processes: (i) enable unconscious goal pursuit with priming (Q4), which has been speculatively discussed in Section 7.4.3.1; (ii) motivate repetition of the goal-directed behaviour to form habit (Q3).

As for the horizontal axis, the cup LED device was designed as an Extended Cognition seamlessly integrated into office workers' lives for a long time to prime goals unconsciously (Q4), the unreliability of the Bluetooth connection and fragility of the sensor case forced it to be a Habit Incubator (Q3). The adaptability of users and their increased automaticity of taking regular breaks suggested the promise of the technology as a Habit Incubator, which has the advantage of less user dependency on the technology. This was because the design, instead of introducing Type 2 reminders, augmented existing office cues for breaks such as empty vessels, or physiological need for hydration.

This suggested two possible directions for future designs of enchanted objects, based on the author's reflection on the design and study of *WorkMyWay*.

One is to position enchanted objects and its companion App in Q4 and Q1, which requires the technology to be very reliable, and well-embedded in an indispensable and indestructible everyday object. Wireless charging may be added to lower the user burdens on managing potentially multiple enchanted objects in the future. It also calls for more product design effort to make the objects look more attractive and loveable, so that users care for them. Then designers may also need to think about different touchpoints for user interactions over the lifecycle of the objects to deliver experience that reengages the Type 2 system if needed. For instance, instead of presenting daily feedback via a mobile app, the system could overlay the feedback on an augmented sink or kitchen top when the user washes the enchanted vessel. In addition, enchanted objects may also be designed to trigger social conversations and enable the cognitive tasks involved in behaviour change to be socially distributed (Hutchins, 1995). It has been argued by Grundgeiger (2014) that a PM task can be partly represented by the environment (i.e. external distribution of cognition) or by other humans (i.e. social distribution of cognition). Hence, the technology can be intentionally designed not only as an environmental representation of the task, but also to be visible to other people sharing the space. The feasibility study illustrated how the task of noticing cues and monitoring for completion of breaks on time could be socially distributed among office mates. Along this line of thinking, an opportunity for future design would be populating an office with various interconnected objects that become salient at different points to represent different needs for work breaks or other PM tasks to facilitate coordination of social breaks.

An alternative is to position the technology in Q3 and Q2, and to intentionally design for short-term engagement. Then the designer will first need to identify existing routines, habits, contextual cues and objects related to the behaviour in the local context, as the author did with the diary-probed interview study (Chapter 5 Section 5.2). Then efforts should be invested to augment existing routines (e.g. tea breaks, water breaks and toilet breaks) and existing objects (e.g. water bottles and cups) that people have already utilised to regulate the target behaviour. The coupling between the technology and the physical artefact can be deliberately loose, so that the technology works to direct attention to the object, but does not act as the cue itself which the new habit is dependent on. Guidance on forming implementation intentions is necessary and useful for the user to make the most out of the period of engaging with the technology. The feedback should focus on shortening the psychological distance of intrinsic reward associated with the behaviour (e.g. make the health goal more proximal with colour-coded feedback), rather than inducing extrinsic reward.

7.5.4 Design requirements for four quadrants

Rather than a panacea, the framework can be used as an inspirational tool for designers to think about where to position their DBCIs in the matrix, and consider the requirements, challenges and questions associated with designing for each quadrant. The following design guidelines (Figure 43) are presented as outcomes of the author's reflection primarily on a single design case of *WorkMyWay*, and speculations about requirements for technology in each quadrant, rather than a prescription for best designs backed by maximum scientific rigour and objectivity.

The key requirement for Q1 technology – Overt Companion is technical reliability and user stickiness. Overt Companions should be able to engage users in the long term, potentially by incorporating social influences and other strategies (for a review, see (Alkhaldi et al., 2015)). This is because technology that is intended to be in Q1 but that ends up in Q2 due to a lack of robustness or user stickiness, can incur a motivational cost (Attig & Franke, 2018) (as shown by the arrow with a cross in Figure 43).

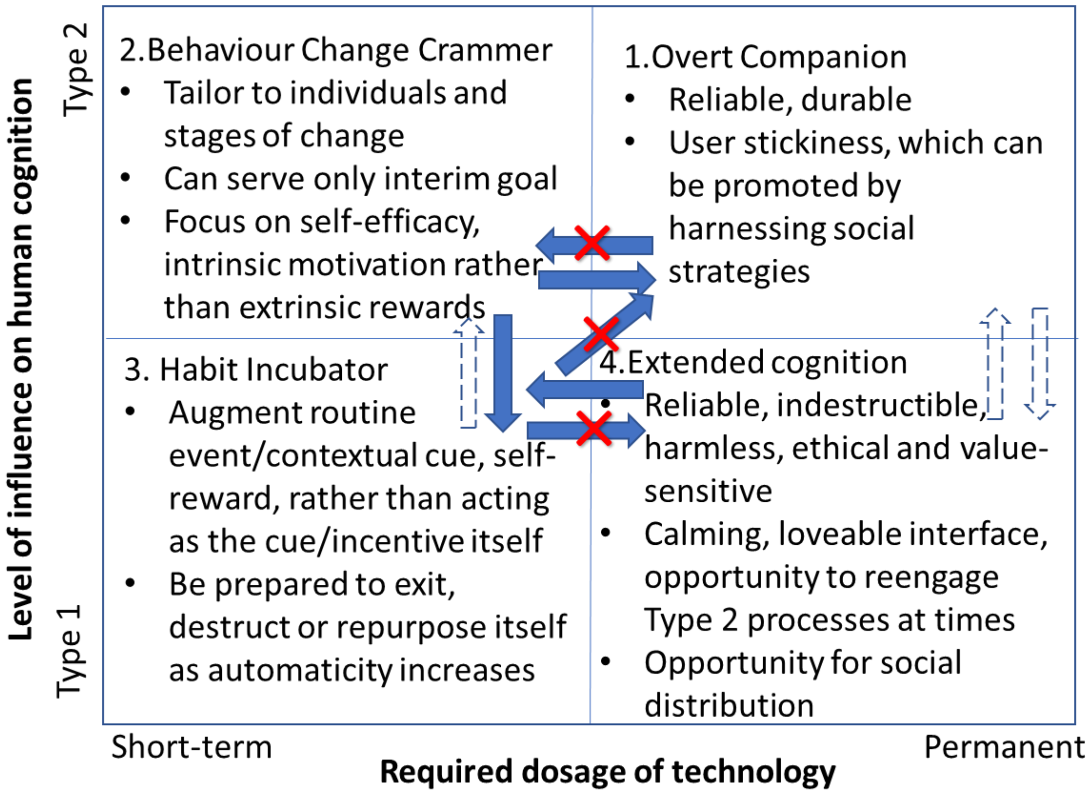


Figure 43 Design requirements for four quadrants

* Arrows with solid outlines represent the direction from where it was intended/designed to be to where it ended up being; arrows with dash outlines meant the acceptable time-to-time transition during use; the crosses indicate undesirable transitions.

A successful Q2 technology needs to tailor to different individuals and support certain stages of change, rather than being overly ambitious. It will also need to cultivate intrinsic motivation and determinations that continue to drive behaviour after technology disuse. Technologies relying on extrinsic rewards and gamification features to motivate behaviour change are bad candidates for Q2. For instance, although the Pokémon Go app worked relatively well to incentivise users to increase walking, it did not cultivate the intrinsic motivation for physical activity that would carry on after the App was uninstalled. If we consider it as a Q1 technology, it did not have the ability to engage its user in the long term, due to issues like draining battery and loss of novelty effect that made people disengage eventually.

A key design requirement for Q3 Habit Incubators is to enable formation of new Type 1 associations that are resistant to extinction even after removal of the technology. For instance, to support habit formation, the technology should increase the salience of the contextual cue and shorten the psychological distance of intrinsic incentive, but not act as the cue or incentive itself. Otherwise, a technology intended to be in a Habit Incubator may undesirably end up as an Overt Companion in Q1, as it stands out too much in the foreground and causes dependency, which hinders automaticity (Stawarz, Cox, & Blandford, 2015). Or even worse, it may undesirably end up as an Extended Cognition in Q4, as the user gets addicted to it and that the removal of technology would provoke anxiety, which is exemplified by the addictive use of smartphone among many users. A good Habit Incubator should focus on augmenting routine events, locations and meaningful objects (e.g. pill organisers) that people had already used for the desired behaviour (e.g. taking medications) to support habit formation (Stawarz et al., 2015, 2017); it should also be prepared to exit, destruct or repurpose itself as automaticity increases.

Compared with Q3, the form factor of Q4 Extended Incubator should be more harmless, calming, reliable, and suitable to penetrate people's lives in the long term, which calls for the loveability, glanceability, indestructibility, and affordability of enchanted objects (Rose, 2014). As Q4 technologies influence behaviours subtly in the long term, they should be designed in an ethical and value-sensitive way (Davis, 2009). It is preferable Q4 technologies are embedded in everyday objects rather taking the form of "cold black slabs" (Rose, 2014) that would eventually aggravate our screen guilts (Skatova et al., 2016). The indispensable nature of everyday objects also means more touchpoints for user interactions over the lifecycle of the objects, which provide opportunities for designing intriguing experiences that reengages the Type 2 system at times and socially distributing the process of behaviour change if necessary. In other words, a technology can be fluid and move around the 4 quadrants.

7.6 Methodological reflection: a hybrid approach to design and study theory-informed digital behaviour change interventions

The methodological strengths and limitations of individual studies have been considered separately in the associated chapters. This section reflects on the overall research process and the author's learnings through tackling the challenges. Although the employed methods are all established tools in their respective fields, the methodological contribution of this research is made through integrating them and reflecting on the integration.

7.6.1 Combining interdisciplinary methods and perspectives

Educations in digital media, social cognition and Human-computer interactions has shaped the multidisciplinary background of the author. The innovative Horizon PhD programme has enabled the author to embark on a journey of research on technologically enabled behaviour change. Throughout the PhD, the author has benefited from having access to multidisciplinary expertise and training resources, including internal training on qualitative research, ubiquitous computing, and external training on systematic review at the Joanna Brigg Institute, and the Behaviour Change summer school run by the inventors of BCW at University College London.

Based on the author's observation, the discipline of HCI and behavioural medicine (i.e. combination of public health science and behaviour change) share a lot of common research practices and values, such as dedication to creating solutions to real-life problems, in-the-wild or field evaluation of concepts and interventions, and being pragmatic and open about drawing methods and perspectives from other disciplines. Although several differences in use of language were noticed (Table 17), they were minor barriers that could be easily overcome with active communication and explanation.

Table 17 Differences in terminologies used by two disciplines

Terms	Meaning in HCI	Meaning in behavioural medicine
"Design and development research"	Draw on formative user research and designers' creativity to design the system, interface and experience	Draw on systematic use of theory, evidence and increasingly PPI approach to design an intervention package that may involve multiple components and determine a mode of delivery
"Implementation"	Technical realisation of the system	1. post-evaluation scale-up in the context of intervention development cycle

		2. intervention delivery in the context of process evaluation
"Feasibility study"	Proof-of-concept study focused on showing whether the design concept or approach is feasible	Focused on feasibility and acceptability of the complete set of research and intervention procedures. Feasibility studies in health research context are more like formal evaluation studies in HCI.
"Evaluation"	A range of lab and in-the-wild studies focused on system reliability, usability, user experience etc.	Studies with a rigorous designs and well-powered sample sizes to establish the efficacy and effectiveness of intervention. RCT is considered the "gold standard".

Hence, at the early stage of the PhD, this research appeared to the author as a sweet spot where two disciplines support and complement each other with research frameworks and techniques. For instance, behavioural medicine offers frameworks to inform systematic use of theory and evidence to inform design, which is increasingly valued by the HCI community. Conversely, HCI offers methods to study and improve the specifics of the technology and examine process measures (e.g. reliability, usability, satisfaction, and quantity and fidelity of delivery), which the MRC has increasingly attached importance to. Third, the emphasis on user and stakeholder involvement in the HCI tradition mirrors the ethos of public and patients involvement (PPI) that has been increasingly advocated in the in healthcare research (Barham, 2011). Finally, while RCT is still considered the "gold standard" evidence in health research, there is a rising emphasis on reporting development and feasibility/piloting studies with process evaluation, as they help identify practical issues, explore context factors, test and tweak all the key uncertainties in the procedure and strengthen the causal links underpinning the intervention (Craig et al., 2019; Moore et al., 2014). Therefore, it was acceptable even under the MRC framework that a PhD could focus on the development phase and culminate with a feasibility study (which would be termed "evaluation" in the context of HCI research).

Conflict or divergence between the two disciplines arose when it came to translating the user requirements and theory-informed requirements into specifications for the technological system and allocating technical expertise to help with the implementation.

Designing and implementing an embedded and connected system could be a challenging, even daunting, task for any novice of IoT technology, even though the author has prior experience in prototyping screen-based user interactions. In addition to electronics engineering, expertise in industrial design and 3D modelling is also needed to make a smart object attractive and "enchanted". The author spent a lot of time to identify, across the industry and academia, a collaborator who possessed the technical skills and found the idea of making a smart vessel to improve office work break behaviours worth the efforts. This was because the technology and interface (i.e. LED pattern) proposed by the author was not fancy enough to excite the HCI colleagues, even though it was suggested by the theory as promising and considered by the stakeholders as useful.

This revealed a tension in this interdisciplinary field of research because of different views regarding the quality and utility of design and research. As mentioned in the scoping review (Chapter 3), a gap exists between the community of HCI and health science (including behavioural medicine), which prevents innovative technologies from going downstream to evaluation and implementation phases. One reason is that health scientists and practitioners will not consider those technologies as viable options unless there is evidence from well-designed feasibility/piloting and evaluation studies. Hence, the author felt an urge to produce a simple yet reliable intervention and establish its feasibility and acceptability with a study following the MRC guidance, so as to introduce smart objects as a novel mode of delivery to the community of health scientists. However, on the other hand, the HCI colleagues would be more excited by a more intriguing and enchanting interaction design than a dull blinking LED. This tension and confusion experienced by the author somehow resonated with the following quote from (Bjerknes & Bratteteig, 1988):

> *"Our experience is that, in the scientific community, technical challenges mean making computer systems that may be characterised as 'epaulets': they have technical fancy features, but not particularly useful. Making small, simple but useful computer systems, more like 'utensils', does not give as much credit event if the development process may be just as challenging"*

Indeed, even though the interaction was simple, the real-time wireless data transmission required for the intervention made the technical implementation particularly challenging and time-consuming, which gave rise to another methodological tension – should we continue internal testing and engineering until the system is reliable? Or, should we deploy a less than perfect system with a bunch of selected cooperative users in the wild to do some research, not only about the usability aspect but also on the promise for behaviour change? It is common and acceptable to carry out iterative and rapid cycles of evaluation and (re)development with users in HCI, because users can have unanticipated responses and new requirements as they integrate the technology into everyday practice. However, it is expected in health science that all technical and usability issues are ironed out before introducing the technology to users (e.g. healthcare professionals, patients, or healthy population for preventive interventions), because of the emphasis on safety and reliability in their culture. This view has started to change in the field of digital health, as technology evolves so rapidly that designs can always be improved (Blandford et al., 2018). Novel evaluation models are also developed to allow simultaneous evaluation of effectiveness and fine-turning of individual components (Collins et al., 2007).

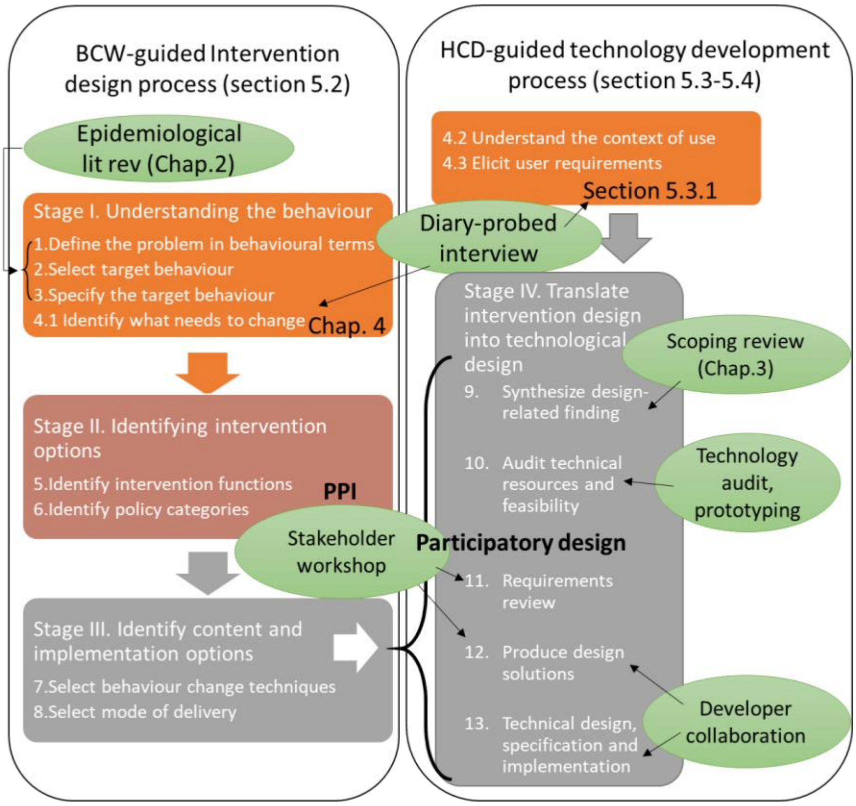


Figure 44 An interdisciplinary approach to develop DBCIs

The process of developing *WorkMyWay* has been summarised into a graphic model to inform future DBIC development (Figure 44). The full 3-stage, 8-step BCW-guided intervention design procedure (the left panel) was performed to formulate the theory-informed design requirements for *WorkMyWay*. Although the HCD-guided technology design (the right panel) is represented as a 4th stage after the intervention design for conceptual simplicity, many of the HCD activities were in practice interwoven with the BCW intervention design process. For instance, the diary-probed interview study did not only serve the purpose of identifying what needs to change under the BCW framework (Chapter 4), but also probed into the context of use and user requirements according to the HCD approach (Section 5.3.1). The stakeholder workshop drew on some workshop-based methods from the HCD approach, but could also be framed as a PPI activity aimed to make the intervention relevant to the target service users (e.g. office workers) in the context of health research. The scoping review (Chapter 3) synthesised design-related findings from previous HCD research, but drew on an established review method from the field of evidence-based health research. Last but not least, most steps were iterative rather than linear. For instance, the intervention design and mapping table was tweaked multiple times based on inputs from Step 8 -13. Those 13 steps are better seen as a checklist rather than a step-by-step recipe.

7.6.2 Applying and developing theories in the wild

Another key area of methodological learning is about making theoretical contributions with an in-the-wild approach. In behavioural medicine, there has been an ongoing endeavour toward scientific reporting of complex behaviour change interventions (Michie, Fixsen, Grimshaw, & Eccles, 2009). The development of the BCT taxonomy (Cane et al., 2015), the TDF (Huijg et al., 2014), and the taxonomy for mode of delivery (Carey et al., 2017) are all contributing toward a behaviour change 'ontology' that ultimately aims to inform systematic and rigorous application of theories of behaviours to address real-life behavioural problems (Centre for Behaviour Change, 2019; Michie et al., 2018). In HCI, there is also an ongoing movement of importing theories about real-world behaviour to interaction design and evaluating interactions in the wild (Rogers, 2011).

The first strength of this research was the use of the TDF/COM-B for the behavioural diagnosis, which has enabled identification of relevant theories in a systematic way. For instance, prospective memory came into the sight of the author through the lens of the

COM-B component of psychological capability and could have been neglected, if it were not for the systematic approach. However, the COM-B is not a panacea, as other studies using COM-B to analyse the same target behaviour in the same population either did not pick up memory as an important construct at all (MacDonald et al., 2018) or did not differentiate prospective and retrospective memory (Munir et al., 2018). This suggests the utility of using COM-B to strengthen the theoretical groundings of interventions is still heavily subject to researchers' interpretation of data and knowledge of literature. In view of that, there might have been other dimensions neglected by the author because of a lack of awareness of the related literature. Nonetheless, the COM-B/TDF has definitely improved the coverage of potentially viable theories of behaviour change.

Another strength of the research is following the BCW to design, describe and evaluate the intervention. As other researchers (Rogers et al., 2010) have noted, it is difficult to separate the effects of intervention and technological components designed to influence people in an integrated way. In this research, the author demonstrated how to assess the individual components relatively in separation by using the intervention mapping table (Table 16) as the basis for process evaluation under the MRC guidance (Moore et al., 2014), and through triangulation of multiple data sources (e.g. psychological measures aligned with the theoretical constructs targeted by individual components, interview quotes on experience and perceptions of each intervention components, and technology-recorded data about usage of different components within the system). The study looked at how people experienced, reacted to and integrated different intervention components in everyday office work, in relation to the BCTs delivered and hypothesised mechanisms of action. Consequently, the author specified intervention components for which mechanisms needed validation or revision or quality of delivery needed improvement (i.e. last column in Table 16).

This approach, summarised in Figure 45, contributes to theory development by identifying what theories and techniques work well out of the laboratory, what are the contextual factors affecting the delivery and effectiveness, and what practical challenges need to be a tackled to improve the fidelity and utility of those theories in the real life.

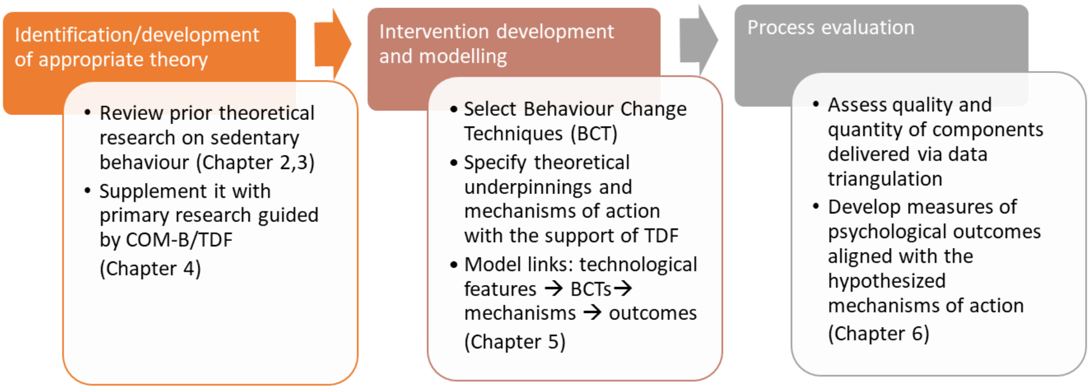


Figure 45 A methodology to apply, study and develop theories of behaviour change in the wild

Two major challenges were encountered with applying the BCW. First, in terms of theory selection, the behavioural diagnosis identified determinants in 11 out of 14 TDF domains, which left the author with a whole range of intervention functions and BCTs potentially viable according to the BCW, which was not very informative. Moreover, the BCW is a new and evolving framework with "loopholes". For instance, according to the framework (Michie et al. 2014, p.114), environmental restructuring is not suitable for addressing the TDF domain of goal. However, prompts/cues delivered with environmental objects should act on goal accessibility, according to literature on environmental activation of higher-order mental processes (Bargh & Ferguson, 2000). The lesson learnt is that, while the BCW is useful for making the links between intervention components, BCTs and theoretical constructs explicit, it should not be taken as a guide to prescribe BCTs to be included or excluded in an intervention.

Second, even though the links are explicit, absolute isolation of effects is still impossible, which can be considered an inherent drawback with in-the-wild studies. As the main purpose of this research was to establish feasibility and acceptability, a before-and-after without control design was used. Moreover, the inability to introspect one's automatic cognitive processes should be considered in evaluation. As theories about automatic cognitive processes are typically revealed as milliseconds differences in response latency, studying them in real-life settings proved challenging. Using validated questionnaire that probes into automatic factors can help, but researchers should also be open about weak causal links that need laboratory validations, without being overly ambitious to prove everything in the wild.

7.6.3 Recommendations for future research practice

The following recommendations for other researchers are based on the author's learning over the process of conducting this research:

1. Frame persuasive technology design research as part of a complex intervention development and evaluation process under the MRC guidance and consider implications for formal evaluation and at-scale deployment/implementation
2. Complement theory-informed intervention design approach with human-centred design methods. This includes building a safe and "minimum viable product" to test with users as soon as possible, not only in the lab but also in the wild, to better the understanding of user requirements and underlying mechanism of action, and iterate whenever needed.
3. Describe behaviour change contents using standardised languages (e.g. BCT taxonomy) intelligible to behaviour change scientists, and make the links between the intervention components, BCTs delivered and constructs targeted explicit.
4. Develop and validate measurements of theoretically-informed constructs as potential mediators, which will help trace the causal pathway and identify effective components in complex interventions and ultimately facilitate the synthesis of knowledge about viable theories of behaviour change (Gardner, Whittington, McAteer, Eccles, & Michie, 2010).
5. Plan process evaluation alongside with intervention design. Include in the requirement documents the type and structure of data needed to be captured in the system to answer process evaluation questions. This would involve operationalising variables pertaining to the fidelity and quantity of delivery of individual intervention components (e.g. usage, dosage, adherence).

7.7 Conclusion

The thesis has explored the feasibility and utility of IoT-enabled smart objects as a mode of delivery for interventions to reduce office workers' SB at work. First, the thesis contributed to the body of knowledge about the target behaviour by identifying a full range of determinants, developing a theory-informed intervention to target those determinants and evaluating it following the BCW. Key mechanisms of action were highlighted, including enhanced self-efficacy, increased automaticity and augmented prospective memory, which can inform the design of future sitting reduction interventions and offer directions for theoretical research on SB. Second, the feasibility study with process evaluation demonstrated the intervention to be feasible, acceptable and promising in real-life office settings, and identified areas for improvements. Several lines of future work to improve and carry the intervention forward to the next stage have been suggested. Third, this thesis led to a conceptual framework to support future designs of UbiComp or IoT systems for sustainable behaviour change, by encouraging designers to consider the type of brain processes their designs are targeting and the required duration of technology use to maintain the behaviours. Finally, by reflecting on the process, the thesis demonstrated a development model combining multidisciplinary methods and perspectives, and a methodology to apply and develop theories of behaviour change in the wild, which can be informative for other researchers working in the field of technology-facilitated behaviour change.

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Appendices

Appendix 1: Scoping review included study and intervention details (Chapter3)

Study	Coded technological features and configurations	Study type and design	Results
(Priebe and Spink, 2015)	ID & MOSSI: email messages containing descriptive norms about co-workers sedentary and light physical activity	Pre-post with comparison groups (2 (personal similarity: high vs. low) ×2(contextual similarity: high vs. low)) n=142	**User-related:** Lower self-report sedentary behaviour, greater stair use and walking were observed in those who received descriptive norm messages about co-workers' healthy office behaviours. No differences between groups.
(Neuhaus, Genevieve N Healy, *et al.*, 2014)	ID & MOSSI: manager's emails promoting the study, noting the progress and providing tips; individual emails summarising goals PDC: activPAL for outcome measurement (for 1 week, baseline and 4-week follow up)	Design & development	**Design-related:** Improvement to each element after formative and piloting phase was reported
(Healy *et al.*, 2013)		Pre-post with control (cluster) (I=19; C=19)	**User-related:** activPAL captured sig. reduction (in I group relative to C) in sitting (-125 min/workday,) and sitting > 30 min (−74 min /workday) and 2 more sit–stand transitions per hour
(Stephens *et al.*, 2014)		Descriptive quantitative (Timestamped activPAL data was analysed to see how and when changes occur)	**User-related:** Sig. reduction (I relative to C) at all hours of the workday, except for 12:00- 13:00. The large differences (≥30% reduction in workplace time spent sitting) were evident before 9:00, 9:00-10:00 and 11:00-12:00
(Neuhaus, Genevieve N. Healy, *et al.*, 2014)	Same as above, except for follow-up schedule: (for 1 week: baseline and 3-month follow-up)	RCT (cluster, quasi-randomised) (I_1(multi-component) =16; I_2(SSD-only) =14; C =14)	**User-related:** Sig. reduction in sitting (-89 min/workday, -56min/workday) in I_1 compared to C and I_2; I_1 group rated additional components and manager emails as useful to very useful. **Design-related:** All I_1 group participants rated additional intervention components as either useful or very useful, and 12/13 rated the manager emails as either useful or very useful
(Healy *et al.*, 2016)	Same as above except for measurement period: (For 1 week, baseline, 3-month and 12-month follow up)	RCT (cluster) (n=231, I=7 worksites, C=7 worksites)	**User-related:** : Sig. reduction in sitting at 3-month (-99.1 min/ workday) and 12-month (-45.4 min/ workday) follow-up

(Brakenridge *et al.*, 2016)	PDC & CD & SP (JITAI): prompts on sitting and posture based on LUMOback belt data connected to smartphone PDC & CD & ATF: LUMOback belt with connected smartphone App for summary on workplace sitting, standing, stepping, breaks; ID & MOSSI: emails delivering information booklet ('Stand Up Lendlease') and feedback on baseline assessment; communicating senior executives' participation and support to employees. PDC: activPAL for outcome measurement (1 week baseline, 3-month and 12-month follow-up)	RCT (cluster) (I (with activity tracker) = 66 (9 teams) C (organisational support only), = 87 (9 teams)	**Design-related:** 70.5% uptake of LUMOback in those provided with the device; variable usage in the first 12 weeks. **User-related**: The following changes were observed within both groups, but only at 12 months: within-work sitting (I: - 35.5 min/workday; C: -40.5 min/workday), prolonged sitting (I: -45.7 min/workday; C: -41.3 min/workday), within-work standing (I: +27.4min/workday; C: +39.2 min/workday). There was no sig. difference between groups on the above. Observed changes in health and work outcomes were small and n.s..
(van Berkel *et al.*, 2011)	'Mindful Vitality in Practice (VIP)' PDC: Actigraph accelerometer for outcome measurement (baseline week, 6-month and 12-month follow-up) MOSSI: e-coaching focused on lifestyle change and mindfulness with certified trainer via Emails ID: email containing information on lunch walking routes.	Design & development (interview (n=6), survey (n=78), focus groups (n=39; 6 groups)	**Design-related:** determinants of PA in leisure time and for SB at work identified as follows: perceived behavioural control, perceived barriers (especially lack of time), and social support; For fruit and vegetable intake, the most important determinants were: habit, perceived behavioural control, availability, cost, and intention.
(van Berkel *et al.*, 2014)		RCT (I = 129, C = 128)	**User-related**: No sig. effect of the intervention on SB, other lifestyle behaviours and behavioural determinants after 6 and 12 months.
(Coffeng *et al.*, 2012)	Be Active & Relax Programme, part of the "Vitality in Practice" (VIP) project, with intervention components similar to van Berker and colleagues'.	Design & development (interview (n=6), survey (n =91), focus group (n=28; 5 groups)	**Design-related:** Determinants of PA identified as follows: attitude, subjective norm, perceived behavioural control, perceived barriers and physical environment; The determinants for relaxation were: awareness, attitude, subjective norm, perceived behavioural control and physical environment.
(Coffeng *et al.*, 2014)		RCT (2 ×2 factorial design, n=412)	**User-related**: Sig. reduction in SB at work were found in the following conditions relative to control: combined intervention (n=92), social intervention (n=118), and physical intervention (n=96); sig. increase in small breaks were found in combined intervention and social intervention groups relative to control.
(Coffeng *et al.*, 2013)		Descriptive quantitative/ process evaluation (monitoring data + survey; n=306, 3 interventions groups)	**Design-related:** the component of step counter reached 50% - 100% of participants and was rated as satisfactory, but were used infrequently; the social media platform component reached 0% -34% of participants, with low satisfaction rating and self-report frequency of use.

(Marshall *et al.*, 2003)	ID & DL & ATF: : fortnightly motivational emails with links to an interactive and animated website with password access and quizzes, feedback on responses, personalised tips on BC strategies over 8 weeks	RCT (C (print)=262, I (web)=250)	**User-related:** IPAQ captured sig. sitting reduction from baseline in Web group (-21 min/workday); **Design-related: Engagement**-half in web group did not view the website at all; lower chance of retaining the material for future reference than print group; a sequential decline of website use and less than 1/2 click-through the link in emails; only 26% log more than once into the website, which were different from previous studies with volunteer participants; **usability -** 9 reported usability issues ; majority were confident about using computer; **preference -** receiving health-related information via email and website is preferred to printed version
(Gilson *et al.*, 2007)	ID & MOSSI: weekly emails containing motivational messages (C), suggested campus walks and maps (route group), tips on increasing steps in the office and in work-tasks (incidental group) PDC & ATF: Yamax SW200 pedometer for real-time feedback on step counts (baseline week and 10-week intervention period)	RCT (waitlist control) (C = 22 ; I_1 (route-based walking group) = 21, I_2	**User-related:** sig. increase in daily step in I_1 and I_2, decrease in C.
(Gilson , McKenna and Cooke, 2008)		Qualitative (interview with 15 participants (7 from I_1, 8 from I_2)	**Design-related:** employees perceived the intervention as an institutional investment in staff; pedometers and weekly e-mail motivational messages provided tangible evidence of the level of investment; **User-related:** also heightened self-awareness of personal health, well-being, and physical activity.
(Gilson *et al.*, 2009)		RCT (waitlist control) (C= 60 ; I_1 (route-based walking group) = 60, I_2 (incidental walking group) = 59)	**User-related:** n.s. group by time interaction for daily recall of sitting time recorded through logbooks at baseline, 1-week, 5-week and 10-week follow-up; sig. increase in daily step in I_1 and I_2, n.s. change in C.
(Parry *et al.*, 2013)	ID: tailored emails with tips on increasing steps in the office and in work-tasks (I_1) and encouraging PA breaks (I_2) PDC: ActiGraph GT3x for outcome measurement (1 week at baseline and 12-week follow-up (end of intervention)) PDC & ATF: Yamax Digi-walker SW700 pedometer for real-time feedback on step counts as a motivational tool (I_2 only)	Cluster stratified RCT (I_1 (active workstation) = 19; I_2 (pedometer challenge) = 14; I_3 (ergonomic training) = 29))	**User-related:** A sig. reduction in the percentage of SB on during work hours (-1.7%, -8 min) with n.s. difference across 3 interventions (I_1 (-3.1%), I_2(-0.6%), I_3(-1.4%)) **Design-related:** Least change in organisations involving call centre and data processing work; feedback indicated interventions were not fully supported by management; call for change in organisational culture.

(De Cocker *et al.*, 2015)	ID & & DL & ATF: Email with link to a website with personal log-in and password, where psychological determinants of SB were assessed with a web-based questionnaire; then advice on reducing workplace sitting divided into sections targeting different aspects of workplace sitting and supporting action planning, tailored to current SB was presented.	Descriptive quantitative (monitoring data + survey) (n=179 contacted; n=47 responded to evaluation survey)	**Design-related: Feasibility and reach -** 90 employees requested the advice website; high education, part-time employment, less than 2 standing breaks/hour, positive attitudes positively predicted likelihood to request the advice. **Acceptability -** The majority found the advice interesting, relevant and motivating. Less than one third believed the advice was practicable. After completing the advice, 58.0 % reported to have started interrupting their sitting and 32.6 % additionally intended to do so; 14.0 % reported to have reduced their sitting and another 51.2 % intended to do so.
(De Cocker *et al.*, 2016)	The same ID & DL & ATF as above for I_1 ID for I_2: automated generic tips on reducing sitting PDC: ActivPAL for outcome measurement (1 week at baseline, 1-month and 3-month follow-up)	RCT (cluster) (I_1(automated tailored-feedback) = 36; I_2 (automated generic feedback) = 64; C (waitlist control) = 28)	**User-related**: Sig. reduction in self-report sitting in I_1 at 1-month (-12min/workday) and 3-month (-102 min/workday) follow-up relative to control group. Borderline sig. reduction in self-report sitting in I_2 relative to control group. ActivPAL did not capture sig. between-group difference in changes in sitting.
(Compernolle *et al.*, 2015)	PDC: blinded pedometer for outcome measurement, 1 week at baseline, 1-month and 3-month follow-up; PDC & ATF: non-blinded pedometer for feedback, 3 months ID & DL & ATF: Email with link to a website with personal log-in and password, where psychological determinants of PA were assessed with a web-based questionnaire; website delivered advice for reaching 10K steps/day, tailored to psychosocial determinants and average daily step counts during baseline week calculated by the researcher	RCT (cluster) (I = 91; C (not receiving any component) = 107)	**Design-related:** 86% requested the tailored feedback; majority rated the advice as interesting, credible, understandable and instructive but also too long. **User-related**: n.s. intervention effect for self-reported SB and PA
(Kerr *et al.*, 2016)	PDC: activPAL for outcome measurement (SB and sit-to-stand transitions), with which the researcher produced graphical feedback, which was reviewed together with the participant in weekly meetings SP (optional tools): timers (phone apps, computer apps), vibrating watch, emails/texts/phone calls from researcher. DL (optional tools): electronic counters to help self-track sit-to-stand transitions	Mixed-methods Two-arm randomised trials (I_1 (decrease sitting) = 15; I_2 (increase sit-to-stand transitions) =15); + Interview	**User-related:** I_1 sig. reduced their daily sitting (-130 min/day), I_2 had no change in sitting time ($p < .001$). I_2 increased their sit-to-stand transitions (+13 transitions/day), I_1 did not. **Design-related:** Recruitment, assessments, and intervention delivery were feasible. Graphical feedback and regular cues to behaviour change (e.g. phone alert) was found helpful; remembering to set reminder and integrating the targeted behaviour change into activities that were outside their daily routines was challenging.

(Aittasalo *et al.*, 2017)	PDC: hip-worn Hookie accelerometer for outcome measurement 1 week at baseline and after the 12-month programme; with which the researcher produced graphical feedback on PA and SB, to motivate participants' wearing and to facilitate goal setting and action planning DL: choice to use a website to monitor their PA MOSSI: choice to use a website to share information with their workmates and friends.	Pre-post (n=296, 12 workplaces)	**Design-related: Fidelity of delivery -** Multilevel implementation at all three levels was applied in six workplaces, while five workplaces implemented actions at two levels and one workplace at one level. **User-related**: Self-report workplace SB decreased from baseline to follow-up (-30min/workday; -22%). Accelerometer measured workplace SB also decreased (-44.9 min/workday;-7.6%). Number of levels or actions had no effect on changes.
(Ganesan *et al.*, 2016)	Stepathlon Programe PDC & DL & ATF: Pedometer for tracking and feedback on step counts; website/mobile App where participants entered daily activity and received interactive advice ID: Daily encouragement e-mails about physical activity and nutrition. MOSSI: online community of participants, with team-based competition and user-generated comments on participation.	Pre-post (n=69219)	**User-related**: Improvements in self-report step count, exercise days, sitting duration (-44,4 min/day), and weight.
(R. LA Freak-Poli *et al.*, 2011)	Global Corporate Challenge ID: motivational emails encouraging increasing step count DL: record step counts via a website or a smartphone application PDC & ATF: pedometer provided outcome measurement and feedback on step counts (throughout the 4-month intervention)	Descriptive quantitative (n=671)	**Design-related**: Reach: employees who started with better health, potentially due to lifestyle or recent behavioural changes, were more likely to respond positively to the program.
(R. Freak-Poli *et al.*, 2011)		Pre-post (n=491)	**User-related**: Sig. reduction from baseline in sitting time (−36 min/workday) immediately after the 4-month programme
(Freak-Poli *et al.*, 2013)		Pre-post (n=315)	**User-related**: Sustained improvements 8-month postprogramme were observed for self-reported sitting time and independently measured blood pressure.
(Freak-Poli *et al.*, 2014)		Pre-post (n=407)	**User-related**: Clinically relevant immediate and sustained (8-month) improvements in wellbeing were observed after participation in the health program.
(MacNiven *et al.*, 2015)		Pre-post (n=587)	**User-related**: Self-report daily sitting time sig. reduced (-21 min/day) from baseline at 16-week follow-up. Pedometer step counts increased sig. between month 1 and month 4, with higher odds of increase in those with low baseline sitting time at work.

(Rabbi *et al.*, 2015)	PDC & DL & ATF: feature extracted from Android smartphone accelerometer and GPS sensor data, clustered into four physical activities based on a machine-learning model—Gaussian Mixture Model (GMM); manually logging physical activities, location and food; real-time feedback on behaviour in the form of a life log (a chronological list of events), including feedback on duration of sedentary and active bouts; prioritize goals based on users' past physical activities and food intake, which include suggestions for reducing SB (e.g. 'take a 3 min break each hour').	Design & development; Mixed Methods (RCT (I (tailored) = 9; C(generic) = 8) + Web-based daily diary + interview + survey)	**User-related:** I group walked significantly more than C over the 3 weeks of the study. **Design-related:** Survey showed personalized suggestions yielded stronger intention to follow than generic suggestions. Interview data suggested users in different stages of change benefited differently. Contemplators: considered MyBehavior suggestions as actionable and relevant to their lives, made then more self-conscious about behaviours; Maintainers: considered the feedback as reinforcement and made them want to change SB in office
(Slootmaker *et al.*, 2009)	PDC & ATF: accelerometer-based Physical Activity Monitor (PAM model AM101, PAM BV, Doorwerth, the Netherlands) is) displayed a cumulative score of PA in real time PDC & CD & ATF: PA score could be transmitted to the software and PAM COACH database via a docking station connected to a PC; PAM COACH website could provide more detailed feedback on progress and tailored PA advice	RCT (I (PAM & Coach) = 51; C (information brochure with PA recommendation=51)	**User-related:** n.s. intervention effect was observed for self-report SB and PA. **Design-related:** satisfactory level of use frequency of the website; only 52% set personal goals; more attention should be given to the quality and appropriateness of tailored advice.
(J. Carr *et al.*, 2014)	PDC & CD & ATF: A seated active workstation with built-in sensing of pedalling activities connected to a desk-mountable display monitor that provides real-time biofeedback on pedalling distance, calories burned and cadence and allows for adjustment of resistance in the range of 1-100Watts.	Design & development (lab study + survey) Phase1: n= 45; Phase 2: n=17	**Design-related:** 96% of participants reported they would use the seated active workstation "daily" if provided access in their office; working while using the seated active workstation increased energy expenditure and had no adverse impact on cognitive performance or typing performance, but it did impair mouse clicking ability.
(Carr, Walaska and Marcus, 2012)	PDC & CD & ATF: In 4-week intervention period, a pedalling device (MagneTrainer mini exercise bike) that could be placed under the desk and provide objective measure of pedalling behaviours (time, distance, calorie, speed); data could be transmitted to PC software which stored and provided feedback on daily performance.	Descriptive quantitative (n=18)	**User-related:** No sig. difference in self-reported SB and PA from baseline. no negative impact on work productivity and quality of work was reported. **Design-related:** High acceptability; Participants used the pedal machines 12.2 days out of 20 possible working days and pedalled an average of 23.4 min/day and consumed 186.5 Kcal/day on days they used the machine.
(Carr *et al.*, 2013)	PDC & CD & ATF: same as above but for 12 weeks PDC & ATF: Omron HJ-150 pedometer for feedback on step counts used in conjunction with the website ID & DL: email reminders to use a motivational website (Walker Tracker) where users logged step counts and receive generic tips and reminders focused on reducing sedentary behaviours throughout the day ID & MOSSI: Online forum for posting profile photos and status updates and sending messages to members of their small groups. PDC: Orthocare ankle-worn StepWatch for outcome measurement (0 steps/min as SB) for 1 week at baseline and 12-week follow up.	RCT (I = 23; C (waitlist) = 17) & descriptive quantitative	**User-related:** I group reduced SB (−58.7 min/day) and reduced waist circumference (-2 cm) relative to C post-intervention, after adjusting for baseline values and monitor wear time. **Design-related:** I participants logged on to the website 71.3% of all intervention days, used the pedal machine 37.7% of all working intervention days and pedalled an average of 31.1 min/day; the pedal machine biofeedback display, the pedometer (ATF) and self-monitoring activity on the website (DL) rated as 'extremely helpful'; the email reminders to log daily activity (ID) and access to the pedal machine rated as 'quite helpful'.

(Sternfeld *et al.*, 2009)	ID & MOSSI: 16-week email-delivered programme that allows the user to choose from 4 to 6 tailored small step goals, which will lead to a personal homepage with tips for achieving the selected goals along with modules; discussion board DL & ATF: A progress tracking tool and simulation tool that gives feedback on the outcome of particular behaviour changes in relation to national recommendations	RCT (cluster) (I (physical activity path) = 195; C=436)	**User-related:** The intervention group (in the PA path) self-reported a decrease in sedentary behaviour immediate post-intervention (-11.3 min/day) and 4-month post-intervention (larger effect than (-11.3/min), but data not shown) relative to control group, based on intent-to-treat analysis. A larger change was observed in those who did not meet PA recommendations at baseline.
(Puig-Ribera *et al.*, 2015)	ID & MOSSI: web pages and emails deliver health facts, motivational messages ('sitting less and moving more') and practical tips on increasing incidental movements and short walks; website provided social networking for sharing experiences PDC & ATF: Yamax SW-200 pedometer for step counts (5 workings days at each of the following stages: baseline (1 week), ramping phase (8 week), maintenance phase (11 weeks) and 2-month post-intervention (2 weeks))	RCT (C (maintain habitual behaviour with access to pedometer, paper diary and self-reporting sitting time) = 135, I=129)	**User-related:** I group decreased self-report daily occupational sitting at end of ramping phase (-20.6 min/day), and maintenance phase (- 23.5 min/day) and at follow-up (-32.2 min/day), increased step counts and decreased waist circumference from baseline; although sig. between-group difference for sitting time (-22 min) only existed at the end of maintenance phase. Step increase was associated with reduced waist circumference.
(Bort-Roig *et al.*, 2014)	DL & ATF: website allows the employee to log daily step counts into a personal account; graphic feedback on progress	Mixed method (n=12 for interview; n=88 for survey)	**Design-related:** 'active work tasks' and 'increases in walking intensity' were the most frequently used strategies; 'walk-talk meetings' and 'lunchtime walking groups' were the least used strategies; 'sitting time and step count logging' was the most important enabler of behaviour change (highlight the motivational value of being able to view logged data (DL) through visual graphics in a website and gain feedback (ATF); 'screen-based work', 'inherent time pressures' and 'cultural norms dictating sedentary work practices' identified as main barriers.
(Puig-Ribera *et al.*, 2017)		RCT (C (maintain habitual behaviour with access to pedometer, paper diary and self-reporting sitting time = 135, I=129)	**User-related: efficiency-related outcomes -** the W@WS intervention attenuated presentism and loss of work productivity in I group across time relative to C group, while having no impact on mental wellbeing. Better performance was linked to employees being more active, and younger, with higher total sitting time during nonworking days and lower sitting time during workdays.

(Carr *et al.*, 2015)	PDC & CD & ATF (16 weeks): portable seated elliptical machine (activeLife Trainer™) under the desk tracked pedalling behaviours, and transmitted data over Bluetooth to an iPod touch with a third-party App installed to provide real-time feedback on pedal time, speed, distance, caloric expenditure ID: informational and motivational emails promoting improved posture, regular breaks from sitting, self-efficacy for physical activity, small changes to the work environment and tips for reducing occupational stress PDC: ankle-worn accelerometer (GENEActiv Original)	RCT (I (integrated health protection/health promotion) =27; C (health protection–only) = 27) + descriptive quantitative/ process evaluation (monitoring data + survey)	**User-related**: I group increased occupational light intensity PA relative to C; adherence and improvements in several cardio metabolic biomarkers (weight, total fat mass, resting heart rate, body fat percentage) and work productivity outcomes (concentration at work, days missed because of health problems) **Design-related**: I group used the activity permissive workstations 70% of all intervention working days and 50 minutes/work day. the ergonomic assessment rated as most helpful, followed by regular emails.
(Donath *et al.*, 2015)	SP: some desktop software popped up dismissible prompts for sit-to-stand transitions at fixed times 3 times /day PDC: ActiGraph for outcome measurement (for 1 week at baseline, 6-week and 12-week follow-up)	RCT (I =15; C (no prompt, SSD-only) = 16) (1-week baseline +12-week intervention)	**User-related**: n.s. change in sitting/standing or n.s. group × time interactions
(Evans *et al.*, 2012)	SP: desktop software (MyRestBreak 1.0) delivers non-dismissible prompts for breaks every 30 min PDC: activPAL for outcome measurement (throughout the study period)	RCT (I=14; C (no prompt, education only) =14) (1-week baseline + 1-week intervention)	**User-related**: Sig. reductions in sitting >=30 min (-1.1 events/workday, -60 min/workday) relative to control; n.s. difference in total sitting.
(Swartz *et al.*, 2014)	SP: desktop software (TimeLeft), and wrist-worn beeping device (Armitron MD0346-R(T)-2) or vibrating device (WobL Watch) delivered dismissible prompts for standing up (I_1) or standing up and walk for at least 100 steps (I_2) every 60 min PDC: activPAL for outcome measurement (for 3 consecutive workdays in the baseline and intervention week); PDC & ATF: Yamax SW-200 pedometer for real-time feedback on step count (I_2)	RCT (I_1(prompt to stand) =29, I_2 (prompt to take steps) =31) (1-week baseline + 1-week intervention)	**User-related**: I_2 sig. reduced avg. duration of sitting bouts and number of sitting >=60 min, but not total sitting; I_1 sig. reduced total sitting (-25 min/workday), longest sitting, number of sitting>=30 min, increased sit-to-stand transitions
(Júdice *et al.*, 2015)	ID & SP: desktop software (Workrave,) delivers non-dismissible prompts every 60 min to take a 7-min walk PDC: activPAL and ActiGraph GT3X+ for outcome measurement (for 21 days in total, throughout baseline, control and intervention periods); PDC & ATF: OMRON pedometer real-time feedback on step count	Randomised crossover (n=10) (1-week baseline + 1-week washout + 1-week control + 1-week intervention with randomised order) + interviews + monitoring data	**User-related**: activPAL captured a sig. reduction in total sitting (-111 min/day) and n.s. increase in sit/stand transitions; ActiGraph captured n.s. change in number of breaks **Design-related**: Interviews and behavioural data suggested people were resistant to increasing breaks, even though they reduced total sitting; 6 of the 10 participants were extremely satisfied with the program; 10 rated step goals as the best strategy (other than screen-based prompts and personally delivered behavioural strategies) to achieve sitting-time reduction; 7 reported leisure-time to be the greatest domain for reducing siting-time.

(Cooley and Pedersen, 2013)	ID & SP: desktop software (Exertime) delivers non-dismissible prompts for breaks and suggests exercises every 45 min for the first 13 weeks; for control period, the participants could voluntarily engage the software DL & ATF: manually enter break activities in the software which provide visual feedback on exercise progress	Descriptive quantitative (13-week intervention + control 13-week period) (n=46)	**Design-related**: employees were willing to participate in a coercive workplace e-health intervention. **User-related**: more activities per day and higher odds of (proxy) compliance (recording more than 6 activities per day) were recorded in passive prompt condition than active condition.
(Cooley, Pedersen and Mainsbridge, 2014)		Qualitative (Interview with 15 out of the 46 participants in a trial)	**Design-related outcomes**: 44 refused to uninstalling the software at the end of study; frustration and difficulty in adjusting to a new work behaviour and annoyance with the passive prompt; although some eventually adapted the way of working, proved to be resilient and accommodating **User-related outcomes**: associated concept of exercising with enjoy and freedom; the tech promoted a sense of discovery; changed perception of what constituted exercise; the changed the environment to afford behaviour change; affected by state-wide competition; personalised feedback supported goal-setting and enhanced motivation; increased awareness and modified behaviour consciously to counteract habitual responses; the software stimulated more social interaction and communication between colleagues and changed the workplace climate.
(Pedersen, Cooley and Mainsbridge,		RCT (I=17, C (maintain) =17) (13-week intervention)	**Design-related**: 100% adherence with no withdrawal throughout the 13-week intervention period **User-related**: OSPAQ self-report captured a reduction in total sitting (-55 min/workday, p value unreported) relative to C group at 13-week follow-up
(Mainsbridge *et al.*, 2014)	Same as above except that C group did not have access to the software	RCT (I = 11; C = 18) (13-week intervention)	**Design-related**: The e-health software prompted participants in the experimental group to engage in NEPA for 7.99± 4.44 minutes per day by performing short-burst physical activities 6.28 ± 3.59 times per workday. The average time for each bout of NEPA was 1.34 ± 0.74 minutes. **User-related**: Sig. decrease in mean arterial pressure in the experimental group relative to control.

(Taylor *et al.*, 2016)	ID & SP (I_2 only): computer software (Workrave, Eyes Relax, and Compact Timer) delivered 5 hourly prompts for 3-min breaks suggesting the user get up and walk hallways, stairs, or outdoors; user can skip or postpone the break. PDC: Yamax SW200 pedometer for outcome measurement (1 week at baseline and 6-month follow-up) DL: user completed daily log on indicating whether they ignored, partially met, or fully met the computer-prompted physical activity breaks	RCT (cluster) (I_1(Booster Break, full programme) = 69; I_2 (Computer Prompts only) = 59; C= 47)	**User-related**: varied results across groups; but overall speaking, consistent attendees of I_1 was observed with a sig. decrease in self-report weekday SB and increase in weekly pedometer counts and weekly energy expenditure. **Design-related (Unintended)**: I_2 showed increased self-report computer use
(Green, Sigurdsson and Wilder, 2016)	PDC: ActiGraph GT3X+ for outcome measurement SP: WatchMinder 3 delivered tactile prompt and displayed text every 30 min, independent of movement. ID: daily email with researcher-curated feedback on prolonged sitting bouts accumulated on the previous workday	Pre-post (n=3)	**User-related**: the tactile prompt plus feedback and goal setting phase was most effective for all participants in reducing the number and duration of prolonged sitting bouts (both >31 and >60). **Design-related**: WatchMinder was worn 89% of those days the researcher randomly visited participants; 100%,
(Mackenzie, Goyder and Eves, 2015)	ID: weekly emails containing educational video, links to reminder software, and tips on sitting reduction and social media to increase awareness; SP: choice to use a break reminder software ID & MOSSI: encouragement emails from management	Pre-post (n=17)	**User-related**: Sitting reduced by 26 min/workday post-intervention from baseline based on sitting log. **Design-related**: intervention was perceived as generally acceptable and feasible for the work context; mixed views of standing/walking meetings; some reported software as useful to keep the idea in consciousness and give ideas about things to try, whereas others reported as distracting. Only 38.5% were aware of this component.
(Bond *et al.*, 2014)	PDC & ATF & SP (JITAI): B-Mobile: Android smartphone accelerometer automatically monitored SB, the data about which was accessed in real-time by the researcher; audible prompt with on-screen text reminder of a 3-min break every 30 min; 6-min every 60 min; 12-min every 120 min; the user had the option to silence or delay the prompt for 30 min; a praising message and "go" badge will appear to reward compliance with prompts and the 'fuel gauge' will be refilled; PDC: SenseWear Mini Armband for outcome measurement based on a combination of movement and physiological sensing data; (throughout the baseline week and 3-week intervention period (1week for each condition)	Randomised crossover design (1-week for each condition) (n=30)	**User-related**: sitting reduced by 47.2 min/day (5.9%), 44.5 min/day (5.6%) and 26.2 min/day (3.2%) in 3-min, 6-min and 12-min conditions respectively relative to baseline; **Design-related**: real-time display and feedback increased motivation to take breaks; siting reduced decreased as a result of the ID and ATF; decrease in SB as a result of using B-mobile; 6-min (n =17) condition as the most preferred condition, followed by 3-min (n=10) and 12-min conditions (n =3)
(Thomas and Bond, 2015)		Descriptive quantitative (use monitoring data to examine behavioural responses)	**Design-related**: the 3- and 6-min conditions resulted in the greatest number and sum duration of walking breaks, the best and fastest adherence to prompts; number and duration of breaks and adherence decreased significantly as a function of days accrued within a condition; high average latency between prompts and break start; 40.9%, 41.4%, and 33.8% of walking breaks were initiated within 5 minutes of the prompt in the 3-min, 6-min, and 12-min conditions, respectively. Conclusion: frequent prompts for small change may be an optimal strategy.

(He and Agu, 2014)	PDC & ATF & SP (JITAI): On11 – An Android app using smartphone accelerometer to classify activities into running, walking, sitting and 'phone on table'; main App screen showed daily activity summary including minutes spent sitting, walking and running; if the user was inactive (sitting or 'phone on table') for 27 minutes in the past 30 minutes, it flashed an LED light on the phone, triggered a vibration or sound, and used a push notification to ask the user to stand up and take a walk	Design & development (2-week field study + open-ended questionnaire; n= 8)	**Design-related: Feasibility -** five found the (in)activity detection accurate when phone was attached to body; long periods of 'phone on table'; battery drained quickly. **Acceptability -** 'at-a-glance' presentation of daily summary was liked; annoyance with the SP - didn't want to be bothered by telling them 'they were inactive' and to take a detour walk too frequently even if they knew it was true; could be encouraged if there was reward and low effort involved.
(Mohadis and Ali, 2016)	PDC & SP (JITAI): WargaFit - A smartphone App reminded users (older office workers) to do stretching after hours of sedentary office work PDC & ATF & MOSSI: the App monitored step counts, provided feedback on the health outcomes of their physical activity and allowed social comparison with colleagues	Design & development (lab sessions with think-aloud protocol, participatory design, parallel prototyping; n=8)	**Design-related:** the system should have contextual awareness, visualise how behaviours would impact on health status, present data that are accurate and reliable, and give user the control over the collection and sharing of their personal health information with colleagues.
(Mukhtar and Belaid, 2013)	PDC & SP (JITAI): SedentaWare - using Android API for activity recognition; if the user had been inactive for > 50% of the last 2 hours, a notification was launched on phone and the threshold was incremented by 10% so that the next reminder would be triggered after being inactive for > 60% in the last 2 hours. PDC & ATF: activity dashboard showed inactive minutes since last activity and reminder countdown; daily, weekly and monthly comparison on activity/inactivity; colour coded icon indicating the need for activity remained all the time visible on the phone's notification bar	Design & development (3-day baseline + 1-week field study, n=4, 2 students and 2 faculty members)	**Design-related:** reminders with adaptive thresholds were more favourably received by users. **User-related:** significant decrease in % of inactivity from baseline after introducing the final version of SedentaWare;
(Grundgeiger *et al.*, 2017)	PDC & SP (JITAI): An Android App combined the gyroscope, light sensors and an existing step counter to detect sitting/standing up/walking; if the user had <2 MET-minutes activity in 30 minutes, the phone vibrated to remind the user to get active, which was repeated once after 90 seconds; if the user was active before 30 min, timers were reset and the user received a silent positive notification.	Design &development (1-day baseline +2-day static reminder + 2-day dynamic App, exit survey, n=5)	**Design-related:** receiving positive notifications from the dynamic App more frequently than from the static App. Sig. difference between 85% subjective and 14% objective compliance rate highlights the need for objective activity tracking measures. **User-related:** significantly less sitting and more MET with the App than at the baseline

(Wadhwa *et al.*, 2015)	PDC & ATF & MOSSI : *SenseX* mobile service captured activities and contextual attributes with smartphone sensors; the App *Standup* visualised daily activities along a timeline, provided feedback on weekly performance, and organisation leaderboard. PDC & ATF: SenseX workstation service tracked keyboard, mouse activities and webcam-based feed and visualised such activity levels. PDC & SP (JITAI): both workstation and mobile services provided onscreen notifications for breaks PDC & CD: used triggered-sensing to replace some mobile sensing with infrastructure sensing and improve battery life; perform sensor fusion for activity inference	Design & development, Descriptive quantitative (8 weeks, n=30)	**Design-related:** mobile and workstation services sensed nearly 50% and 25% of the total time respectively; triggered-sensing could increase the battery life time by nearly 25% of the time. Based on response time, there was a slight preference for mobile-based notifications over workstations ones; long tail of longer response times was observed because participants did not carry their mobile phones when they took a break. **User-related:** increased step counts and recued sitting sessions/durations were observed from week 1 to week 6 (no baseline info); for nearly half of the notifications, participants acted in less than 10 minutes.
(Van Dantzig, Geleijnse and Van Halteren, 2013)	Study 1 PDC & SP (JITAI): an Android App (SitCoach) using on-board accelerometer of smartphone to track inactive minutes; the phone vibrated or buzzed after a configurable amount of inactive minutes (60 min by default) PDC & ATF: the App displayed accumulative daily active minutes and countdown until next break	Design & development (1-day use of App + interviews, n =8)	**Design-related outcomes:** tactile feedback is preferred to acoustic alert; main barrier to break is perceived lack of control over their sedentary breaks, which was also source of annoyance with PC break reminders; smartphone battery drains quickly with accelerometer running
	Study 2 PDC: software tracking mouse and keyboard movements for outcome measurement; commercial monitor (brand unknown) for PA outcome measurement (baseline week and 6-week intervention period) PDC & CD & SP (JITAI): mouse and keyboard movement was tracked and uploaded to a backend server which sent text messages to phone containing hyperlinks to persuasive messages for breaks in every 30 minutes of computer activity PDC & CD & ATF: commercial PA monitor data could be uploaded to the computer via USB cable and a personal webpage for feedback on activity pattern	RCT (I=40; C (no break prompts) =46))	**User-related outcomes:** message leads to Steeper post-message decrease in computer activity in intervention group than control; seems to have post-message peak in PA, but n.s. difference from control; **Design-related outcomes:** no larger effect in those reading > 50% of messages, which suggests that the content of the persuasive messages is unimportant, receiving a timely reminder on their smartphone might be sufficient)
(Davis *et al.*, 2009)	PDC & SP (JITAI): Workpace™ software monitored key strokes and mouse movement, work intensity and compliance to break (e.g. no keyboard or mouse activity), reminder software delivered dismissible prompts every 30 min, participants had the freedom to follow or ignore prompts. PDC: video camera were set up for outcome measurement (in the last 2 weeks of each condition)	Randomised crossover (each of the four conditions was evaluated for 1 month; n=35)	**User-related:** reminder software had the largest impact on discomfort reduction and even increased productivity

(Ferreira *et al.*, 2014)	PDC & CD & SP (JITAI): A desktop system (BreakOut) used webcam to track posture, keyboard/mouse sensor to track computer activity delivered just-in-time prompts via a sculpture built on the Arduino platform ID: using desktop wallpapers and a sculpture to display information on need of a break	4-day field study with validation data from Experience Sampling (n = 10)	Sig. correlation between self-report and inferred posture, stress and engagement; posture and stress, but not engagement predicts need of a break.
(Van Almkerk *et al.*, 2015)	PDC & CD & ATF: Backtive - a chair (built on Arduino) with embedded push buttons and pressure sensor capturing pressure distribution; data was transmitted to a laptop with a cable; data was then sent to smartphone application that provided visual feedback on daily sitting time and posture. PDC & ATF & SP (JITAI): chair provides tactile feedback (pumped air cushion at the back) for just-in-time posture correction DL: user input the amount of pain experienced in the smartphone application	Design & development (2-hour lab testing + questionnaire; n=4)	**Design-related:** survey suggested participants had high behavioural intention to use Backtive, expected it to be easy to use; there is room for aesthetic improvement
(Gilson *et al.*, 2016)	PDC: Sitting Pads with pressure sensors developed by the University for outcome measurement (baseline week + 5-month intervention); GENEActiv wrist accelerometer (baseline week & the last week in the intervention period) I_2 Group Only: PDC & CD & ATF: proprietary software that linked to the Sitting Pads to download data and summarised duration of total sitting and longest sitting bout PDC & CD & SP (JITAI): software prompts moved from Green to Amber and then Red repetitively after 30 min and then 60 min of continuous sitting (user can tailor the time threshold and opt-in for additional auditory prompts)	Pre-post with comparison group (I_1 (participatory only, no prompt)= 33, I_2 (prompt + participatory approach) = 24)	**User-related**: GENEActiv captured sig. sitting reduction (-54 min/day) in I_2 relative to I_1. Based on Sitting Pads data, there was sig. reduction in total sitting (-23 min/day) and longest bout sitting (-32 min/day) from baseline in I_2 relative to I_1.
(Jafarinaimi *et al.*, 2005)	PDC & CD & SP (JITAI): a prototype system built on the Parallax Basic Stamp Board of Education included a chair cushion with conductive sensor that captured sitting time and a sculpture with servo motor that changed its shape after 60 and 90 minutes of sitting to prompt standing. ID: sculpture delivered information on the harm of prolonged sitting	Design & development (interview + baseline week + intervention week + post-study interview, n=1)	**Design-related:** Demonstrate its technological **feasibility** and **acceptability**; users appreciate the non-intrusiveness and aesthetics. **Behavioural outcome:** there is relationship between the sculpture movement and user's break times. Long-term experiment is needed.

(Haller *et al.*, 2013)	PDC & CD & SP & ATF (JITAI): a prototype of intelligent chairs that classified sitting into 8 postures based on four force transducers, was connected to three options of devices for three types of feedback: 1) graphical: onscreen digital prompts for exercise; 2) physical: mechanically controlled physical plants; 3)vibrotactile: vibrations and buzzes	Lab study with within-subject design (1.5 hours for all conditions, n=12)	**Design-related**: Less postponed responses to prompts in editing task than in transcription and planning tasks; vibrotactile feedback led to shortest response time than other feedback, but was rated as the most disturbing form of ongoing feedback. *Physical feedback* was rated as least disruptive to workflow, least disturbing form for providing ongoing feedback/alerts, and also required the shortest time to return to the main task after the prompted activity; time to return to the primary task was longest under the digital feedback condition.
(El-sayed *et al.*, 2011)	PDC & CD & SP (JITAI): a bulky wearable prototype system that consisted of weight sensors in shoes measured the strain placed on each foot to detect prolonged sitting and standing in fixed positions, inclinometer at the neck measured bending angle of upper back, a WiFi device transmitted sensor data to a base station. The system sent SMS message to user when sustained bad posture was detected ATF: desktop interface provided real-time feedback on posture and daily time spent standing, sitting or walking; summary report was also sent by email at the end of the day.	Design & development (Lab testing; N unknown)	**Design-related**: accurate detection of both poor back posture and prolonged sitting/standing (technological feasibility); bulky wearable components need to be downsized (practical issue)
(Fortmann *et al.*, 2013)	PDC & CD & SP & ATF (JITAI): MoveLamp system - an Android smartphone with pedometer application transmitted step counts to a desktop application via Bluetooth; desktop app calculated colour value and manipulated the colour of an ambient light display via radio transmission; bright red signified 2 hours of no steps and suggested the need for a break; 500 steps would restore it to dark green. PDC: pedometer data for outcome measurement	Randomised crossover (1-day control (pedometer App only) + 1-day intervention; n=10)	**User-related**: ambient light feedback on inactivity helped people to both move more frequently and increased overall daily steps.
(Mateevitsi *et al.*, 2014)	PDC & CD & ATF & SP (JITAI): HealthBar – An Arduino controlled light tube changes colour from green to red, corresponding to the length of the user's sitting period, which was captured as presence at desk by passive infrared motion sensors; after 45 min of sitting, the tube will pulse twice every 5 min to prompt a break in sitting; the bar can be reset by taking a 5 -min break.	Design & development (5-day field study + pre- and post-study questionnaire; n=8)	**Design-related**: All agreed the participants was easy to understand and make sense; all would like to continue using the system; perceived as "helpful" and "interesting". **User-related**: 4 thought it was a light distraction, 3 thought it was not a distraction; majority reported increased awareness of unhealthy sitting habits and breaks as a result of using the system
(Reeder *et al.*, 2010)	PDC & SP (JITAI) (scenario and concept): After 45 minutes of sitting, the Arduino-based Breakbot' fibre optic ear tufts blinked red and retracted into its head to express displease and tiredness; vibrated after another 15min of inactivity; and waved tufts to show happiness if the user took a break. IP: use animated features to express robot's emotions	Design & development (interview(n=6), diary(n=3), survey (n=16))	**Design-related**: Preferred form of robots spanned the range of minimal to creature-like; the minimal form of prototype was met with enthusiasm, though size and portability was a concern; personalisation would be valuable; showed emotional investment in the robot's welfare.

(Obermair *et al.*, 2008)	PDC (Wizard of Oz) & SP (JITAI): perFrame – researcher observed user's sitting posture via a camera and controlled an electronic photo frame via WiFi to display selected video footages ID & MOSSI: in the videos, either an actor or the user's close friend perform gestures and expressions to show approval/disapproval for the user's sitting behaviours.	Design & development (half a day + interview, n=8)	**Design-related:** users rated the interface as pleasing and useful; but could not always comprehend the meaning of the portraits of a unfamiliar actor; high likability and comprehensibility of a close friend's videos compared with an actor's; there was also a lack of consistency in standard for good vs. bad posture; when the portrait performed a gesture, they noticed; it was not distracting and glimpses were voluntary

I: Intervention
C: control or comparison

Appendix 2: Promotional material for the diary-probed interview study (Chapter 4)

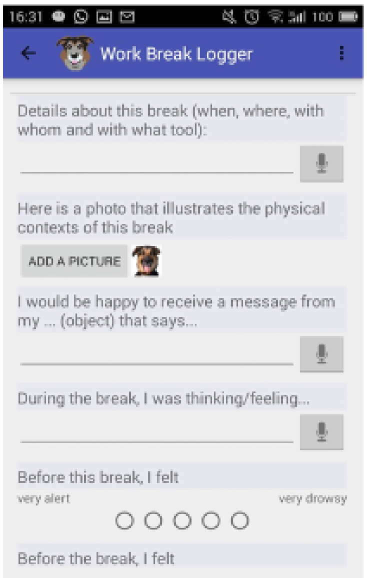
Log your work breaks & earn £25

Eligibility:

- >=18 years old
- Office-based job which you would label as **sedentary** (chair-bound most of the day), or **semi-sedentary** (intermittently chair-bound and moving around but without substantial walking or physical labour)
- No significant mobility problems

Procedure:

- Attend a briefing session (30 min)
- Log your work breaks and submit illustrative photos for 2 days
- Attend a debriefing interview (60 min, your break logs will be discussed in the interview)



Reward:

- Knowing more about your work-break patterns
- A £25 Amazon voucher

Sign up here:

https://goo.gl/Jz0xFm

work break study: https://goo.gl/Jz0xFm psxyh1@nottingham.ac.uk	work break study: https://goo.gl/Jz0xFm psxyh1@nottingham.ac.uk	work break study: https://goo.gl/Jz0xFm psxyh1@nottingham.ac.uk	work break study: https://goo.gl/Jz0xFm psxyh1@nottingham.ac.uk	work break study: https://goo.gl/Jz0xFm psxyh1@nottingham.ac.uk	work break study: https://goo.gl/Jz0xFm psxyh1@nottingham.ac.uk	work break study: https://goo.gl/Jz0xFm psxyh1@nottingham.ac.uk	work break study: https://goo.gl/Jz0xFm psxyh1@nottingham.ac.uk	work break study: https://goo.gl/Jz0xFm psxyh1@nottingham.ac.uk	work break study: https://goo.gl/Jz0xFm psxyh1@nottingham.ac.uk

Appendix 3: Online sign-up and screening questionnaire (Chapter 4)

Occupational Sitting and Work Breaks in Office Workers
Participant Sign-Up

Please complete this form if you would like to participate in a research study that will involve a 20-min briefing session, keeping a diary for 2 workdays and a 60-min debriefing interview. Answers to questions here are used to check your eligibility and schedule the initial briefing session with you. You will be compensated with a £25 Amazon voucher at the end of the interview.

For inquiries, please contact yitong.huang@nottingham.ac.uk.

Full name:

Contact details (email and/or phone):

What is the highest degree or level of school you have completed?

Please briefly describe your job (both the type of industry/organisation and your job role/title):

How many hours did you work in the past 7 days?

During the past 7 days, how many days were you at work?

How would you describe your typical work day in the last 7 days? (This involves only your work day, and does not include travel to and from work, or what you did in your leisure time). Make sure it adds up to 100%

sitting	0
standing	0
walking	0
heavy labour or physically demanding tasks	0
Total	0

Do you have the freedom to take regular mini-breaks/comfort breaks if you want to?

Never	Rarely	Most of the time	Always

How many times do you sit continuously for over 60 min before standing up during working hours on a typical working day?

The researcher would like to visit your workplace to do the 30-min briefing. Please provide your office address and convenient times (could be lunch time or after work hours):

office address

preferred time slots:

>>

Appendix 4: Information sheet and consent form (Chapter 4)

Diary and Interview Study on Work Breaks – Participant Information Sheet

Please take your time and read both the information sheet and consent form carefully before signing. Please retain one copy of this document for your own use. You are encouraged to ask the researcher questions, if anything is unclear.

This study is part of a PhD research project on designing digital technologies to enhance workplace health and wellbeing among office workers. You have been selected to participate as a potential user of such designs. The focus of this study is on understanding the work and break routines of office workers during office hours, what encourages and hinders you to take breaks, and what objects are involved in your experience and decision about taking breaks at work.

This briefing will last approximately 30 minutes, during which time you will be asked some questions about your work breaks and demographic information.

You will then be given a specially-designed diary to keep a record of your work break patterns and experience for 2 days. You are encouraged to take photos of objects and physical settings related to your work breaks during those 2 days.

You can choose to use the paper form or/and a smartphone app called PACO to log each break experience. If you don't have a smartphone, you will receive a free loan of a smart phone for the duration of the study period for taking pictures (and logging breaks, if opting in). You will also receive detailed instructions from the researcher if you decide to participate.

After 2 days of the diary study, the researcher will come to collect your completed diary materials and schedule an interview. It will be up to you what images to share with the researcher. You will then attend a 1-hour debriefing interview out of office hours, which will be audio recorded. It will mainly involve you talking the researcher through your workdays, using your diary and photos as memory prompts.

You will be given a £25 Amazon voucher to compensate for your time in taking part in the study at the end of the debriefing.

Your data will be securely stored on the University research drive only accessible by researchers involved in the study, in accordance with the Data Protection Act 1998. If you opt to use the PACO app, your break experience entries will also be stored on the PACO server, only accessible by the researcher. These data will be deleted from PACO server after it is transferred to the University research drive at the end of the study.
Your data collected from this study will be analyzed to generate insights to inform the design of some “enchanted objects”, for example, a smart mug that learns your pattern and subtly suggests tea breaks at opportune moments. You can opt in to keep informed about the development progress and participate in further studies on evaluating the design.

Your data will also be analysed and written up in research publications by the researcher. Unless you have given specific consent for data to be published that could identify you, all data reported in publications will be made anonymous (face and identifying information will be blurred). Any information about you will be described under a pseudonym.

Publishing data will result in information becoming available through the internet to anyone who wishes to access it through scientific libraries related to this research (for example the ACM digital Library).

Your participation in this research is entirely voluntary. You may withdraw your consent at any time either during or after the study by contacting the researcher, without explaining the reason and without consequence. In this event all data collected up to that point will be erased.

This study has been approved by the Computer Science Ethics Committee (CREC) of the University of Nottingham. The researcher is supported by Horizon Centre for Doctoral Training at the University of Nottingham (RCUK Grant No. EP/L015463/1) and Unilever UK Ltd.

For any inquiries please contact: Yitong Huang (Tel: +44 (0) 7821475752, Email: yitong.huang@nottingham.ac.uk, School of Computer Science, The University of Nottingham, Wollaton Road, Nottingham, NG8 1BB)

Diary and Interview Study on Work Breaks – Participant Consent Form

This is to confirm that I have agreed to take part in a research study conducted by Yitong Huang. I have read the information sheet provided and I understand what is involved.

I freely give my consent to take part in this study. I am a consenting adult over 18 years old and if I have any disability that will require adjustments to be made to the study I will make the researcher aware of these prior to the study. I understand that I have the right to withdraw from the study at any time by contacting the researcher without giving a reason.

I understand that photos I take and submit to the researcher will be viewed and analysed by the researcher and the researcher's supervisors; and if I don't want them to see any images I should delete them before transferring photo data to the researcher.

I understand that that my data collected in this study will be stored under the Data Protect Act 1998 and be used anonymously in publication. I have the right to ask for my data to be removed from potential publication submission up to the point of study write up, although once it is published it can no longer be removed

Please read the following statements below and select your response by ticking the appropriate boxes:

YES ☐ NO ☐	I have received a smartphone on loan for this period. I undertake to ensure that this is kept safely and securely and to return it in good condition at the end of the trial.

YES □ NO □ I understand that if I choose to use the PACO app for break logging, data will also be stored on the PACO server during the study period.

YES □ NO □ I consent to my debriefing interview being audio recorded and transcribed.

YES □ NO □ I consent to my questionnaire, diary, photo and interview data being analysed and reported aggregately and anonymously in publications and presentations.

YES □ NO □ I consent to my interview data being referred to in publications anonymously.

YES □ NO □ I give permission for my photo data with no identifying information, or with identifying information blurred to be included research publications and presentations.

YES □ NO □ I also give permission for photos that could identify me to be used in research publications and presentations (This is an **optional** point; please do not tick it if you object to this)

YES □ NO □ I would like to receive invitation to participate in future studies for the “enchanted objects for healthier work breaks” project.

Signature of Participant: .... Date: ....

Print Name of Participant: ....

I have explained the study to the above participant and he/she has agreed to take part.

Signature of Researcher: .... Date: ....

Appendix 5: Pre-study survey protocol (researcher-administered) (Chapter 4)

Name: __________ Age: _______________ Gender: _________________

Email: ________________________________

Job title and role: ________________________________

- Do you normally have the freedom to take a mini-break if you want to?

Organisation and department: ____________________

Education level________________

Weight__________ height___________

- OSPAQ (if different from online screening)
- What's the average interval of your breaks (each interruption in sedentary work is considered a break, can be in the form standing from a sitting position, stretching legs, getting printouts, taking a walk etc.)

I take breaks every_____ minutes.

- Name a few of your break activities? Where, with whom and involving what objects?
- Is there any gadgets or tools you use for reminding yourself to take breaks at the moment?

Appendix 6: Diary protocol and materials (participant self-administered on paper) (Chapter 4)

For each study day, you need to

1. Use the **"Workday Episode"** form to record your workday as continuous series of **"episodes"*,** like scenes in a film. Give each episode a brief note that will help you remember it. Write down the approximate times at which each episode began and ended.
2. On top of that, for each **non-sitting episode**, you need to
   1) **take a photo** that illustrates the physical contexts (tools and products used, location, environment) of each event while you are in the situation
   2) complete the **"Work Break Experience Form" **** (either paper or e-version, please tick the format you have completed)

* Episode: In this study, an ***episode** is a continuous engagement in a certain activity with unchanged posture (e.g. sitting or non-sitting).* So you are expected to *log the start and end time of an **episode** whenever you leave and return to seat.* The episodes people identify usually last between 15 minutes and 2 hours and can take the form of an uninterrupted period of sitting, a short bout of comfort break and a longer bout of lunch break.

Break: In this study, the term **"break" refers to any termination in sedentary time (i.e. any activities you engage while not sitting). Even if you stand just briefly (e.g. stretch out, tidy up your desk, and talk to colleagues over the cubicle wall), it's considered a break; or even if you stand up and move about for work-related purposes (e.g. print & photocopy, collect parcel, visit another office), it's also considered a break. In the occurrence of any of the above "breaks", you are expected to take a picture and complete a "**Work Break Experience Form".**

#Sedentary breaks: You might have respites in your seat (e.g. checking Facebook, watching a YouTube video at desk over lunch), please report those under the question "What were you doing in the previous sitting episode?"

##Enchanted objects: imagine you are in a futuristic sci-fic world where everyday mundane objects can understand your needs and talk to you.

Workday summary - Sample

Participant ID:		Date :				
Starts work at:			Finish work at:			
Workday Episodes						
start time (hh:mm)	end time (hh:mm)	event name	photo	Paper form	Excel form	App form
12:00	*13:42*	*Work*				
13:42	*14:30*	*Lunch*	✓	✓		
14:30	*14:32*	*Toilet*				✓
14:32	*14:38*	*Make tea*	✓			✓

Work Break Experience Form – Sample

break starts at: ...10:10...	break ends at: ...10:25...	With photo?	Yes ~~/ No~~

What has triggered you to leave your seat?
I left my seat because... *I need to print out some document, but part of me also knew I need to stand up and refresh my mind* I left my seat because...*my colleague wanted to have a chat over a coffee*
hint: the trigger could be an event, an environmental cue, or a subjective motive

Do you have any idea how long you had been seated for before this break?	
Yes ...*60*....... minutes	No
What were you doing in the previous sitting episode? #	
I was *working on 2 projects. checked Facebook and Amazon in between & snacked*	
hint: please briefly describe how many pieces of work you did, if you were multitasking; and whether you took any mini-breaks without leaving your desk (e.g. check facebook, handle personal chores) in between.	
Do you wish you had taken this break earlier or later? Why?	
~~Earlier/~~Later. Because... *I got so many things to do and if it were not for my urge to go to the toilet, I would have kept going.* Earlier~~/Later~~. Because... *I knew it would be good for me to refresh my mind. But I was so absorbed in work and lost track of time*	

Please provide details about this break:
I ... *print out documents & check email on my phone -> make a coffee -> toilet*
I ...*walk for 5 minutes to buy lunch --> eat lunch at desk & read emails on screen*
hint: please first take a photo to illustrate the context (when, where, with whom and with what tool), then describe sequence of actions (joint by "-> ") or concurrent activities (joint by "&") and explain the context in words, where necessary

What message would you like to receive from your enchanted object(s)## and in what context?
When... *I was sitting for over an hour*..., I would like my......*mug*.... to say to me: *Hey, you've been sitting for XX min! Why not fill me up? You deserve a tea break, buddy!"*

Note down any thoughts going on in your mind during this break:
I was thinking about... *what to do next because I have so many things to do today.*

Please rate	before the break	Now
1 drowsy, 5 alert	*1*	*4*
1 anxious, 5 relaxed	*2*	*4*
1 sad, 5 happy	*3*	*3*

Work Break Experience Form

break starts at:	break ends at:	With photo?	Yes / No

What has triggered you to leave your seat?
I left my seat because...

Do you have any idea how long you had been seated for before this break?	
Yes ...... minutes	No
What were you doing in the previous sitting episode?	
I was...	
Do you wish you had taken this break earlier or later? Why?	
Earlier/Later. Because...	

Please provide details about this break (e.g. what, where, how and with whom):
I ...

What message would you like to receive from your enchanted object(s) and in what context?
When..., I would like my............ to say to me:

Note down any thoughts or comments going on in your mind during this break:
I was thinking about...

Please rate	**before the break**	**Now**
1 drowsy, 5 alert		
1 anxious, 5 relaxed		
1 sad, 5 happy		

Appendix 7: Interview questioning route (Chapter 4)

The retrospective interview at the end of the 2-day study period will be semi-structured. Questions are likely to vary across individual respondents depending on images collected. The following questions are illustrative of the type of information to be gathered from interviews.

Theme (***Heading***), opening and transition questions (regular), *sub questions* (italic).

Study experience and reflection on diary

What's your experience of taking part in the study, apart from the object?

- *Did the action of keeping a diary and taking photos change your behaviour in any way?*
- *Did you look at your own diary materials at the end of each day? How did you feel then?*

Discussion on occupational sitting

Ref Mot (Beliefs about consequences/capabilities):

Compare two work break styles: *given the same amount of total sitting, which of the two do you think is better? Why?*

- *What benefits do you hope or believe it Style 2 has?*
- *What harms do you think Style 1 has?*
- *How easy or difficult do you think it is to do style 2?*

Here are some graphs and statistics about your two days. Is there any surprise? What do you think? Fix data

Ref Mot (beliefs about consequences/capabilities, intentions, goals):

So what do you think of your current amount of sitting everyday?

- Do you think that's too much or just alright? What impact do you think it has?

Psychological capability (Memory, attention, decision processes):

- If it were not for this study, would you always remember how long you've been sitting? How easy or difficult do you find it to keep track of how long you've been sitting at work

Psychological capability (Knowledge): What do you think would be the ideal work break pattern for you? How certain are you about it?

What's good about it?

1) productivity at work,

2) mood during the workday,
3) energy level at the end of the workday
4) physical health and fitness

If mention a lot about regular breaks:

- *How attractive are those benefits? / Would the benefits of this ideal work break pattern be rewarding enough for you to make a change?*
- **Intention:** *Is taking regular breaks something you generally intend to do? If yes, on a scale of 1-7, how effortful do you feel it is to keep doing it?*

  When you sit for longer than 60 minutes, what prevents you from breaks?

If mention none about breaks:

- o *are you aware of any harms of sitting for over 60 minutes at a time during work? (short- vs. long-term consequences)*
- o *Are you convinced that taking regular micro-breaks have significant health benefits?*

Goal: Have you set it as a goal to stop sitting for too long? Compared to the goal of completing your work, to what extent is taking regular breaks throughout working day a priority for you? What about keeping health in general?

- ***Spy cap (Decision/attention/memory):*** *do you tend to think about those benefits we talked about during work?*

Self-identity: Do you see yourself as someone who pays attention to one's own health and fitness? Do you see yourself as a workaholic?

Facilitators/barriers

Objective (organisational/social)

How difficult or easy do you think it is to find time to take a little break?

Is there any work that requires long period of concentration to get into the flow?

Are there any other factor that prevents you from taking breaks away from desk?

What's the culture of work breaks like in your workplace?

- *How do you think your manager/ supervisor perceive taking regular breaks away from desk? Are they approving or discouraging?*
- *What about colleagues? Do you feel part of a "crowd" when taking*

Subjective strategies (psychological capability):

Decision/automatic mot: Is XXX something you usually do? *Did you plan it? Or was it a random act? Or is it like a habit?*

Behavioural regulation: *Do you set any rules for yourself regarding when you should stand up and move around?* Do you set any triggers to prompt yourself?

Self-Monitoring*: Do you have system to help you monitor whether you have taken regular breaks on work days? Would you find visual feedback on your sitting and breaks, like the graph I produced, helpful?*

Potential technologies: Do you have any technologies or tools that tracks your period of inactivity?

Would you find it helpful to have a piece of technology that 1) monitors and displays your sitting time 2) send idle alert?

Potential interventions: *e.g. How would you feel about standing up and talking to your office mate? Or whenever someone comes to talk to you, you stand up?*

Automatic motivation:

- Habit: Would you say that generally you are in the habit of sitting for over 60 minutes/taking regular breaks? If not, what would be helpful in developing/breaking that routine/habit?
- Does taking a break evoke an emotional response?

Break activity/contents – Automatic Motivation

Do you have much choice over what to do during your breaks?

Can you think of a particular work break activity that can recharge your energy effectively and benefit your health?

- *Would it occur to you do to this activity when you need to take a break?*
- *Would a tool that suggests break activities be helpful to you?*
- From your images, I can see you do…. *From images, you seemed to stand up while […carrying on working on screen, paperwork (e.g. filing), talking on the phone/checking phone messages, stretching out].* Did I miss anything?

Let's think of out the box. What other activities you would like to do during work breaks, if we forget about the physical constraints your current workplace may have? **Physical Opportunity/Automatic motivation**

What facilities do you have access to in the workplace during work breaks at the moment? What other facilities do you want to have easy access to? Physical Opportunity

Do you feel your break time **experience** itself is rewarding enough at the moment? How do you think your break time experience can be enhanced?

Beliefs about capability: how confident do you feel about forming a habit of taking more regular breaks and shortening your average sitting about, with the support a technology that has the features we discussed?

Potential design

If you can design an intelligent system with any kind of objects that remind you to take breaks, what features would you like it to have?

Approaches:

Remind to take breaks based on idle time: How would you feel about being interrupted at work with a recommendation to take breaks from sitting?

Change content: no one asks you to take breaks; but you have a “break” manual that suggest activities to keep you more active within the breaks you usually take?

Detect fatigue: …

Objects:

Your XX seemed quite central in your work breaks, how often are you not around your water bottle. What about mugs? Did you use one or more mugs?

What about this - a smart water bottle with an embedded sensor that captures your sitting time and step counts, and it communicate to you about your physical activity level.

Would you find such an object pleasant or annoying? Would you keep using it?

Preferred medium:

Prefer to receive in what context?

Potential for personalisation?

What tone of voice you would like your object to speak to you in?

Appendix 8: Individual worksheet for the design workshop with stakeholders (Chapter 5)

Individual Worksheet **Your Name: ____________**

COM-B	Statements on office workers' barriers and facilitators to breaking up sitting with hourly micro-breaks in the workplace	To what extent does this reflect what you've observe in your workplace? (1-not at all, 5-very)	How important do you think this factor is in determining micro-break behaviour? (1-not at all, 5-very)
psychological capability	Easily lose track of time when engrossed in work		
	Don't attend to bodily needs for breaks		
	No idea of the total number of breaks or episodes of prolonged sitting that have happened during a day		
	The decision to take a break or not needs to consider progress with the current task, physical and mental fatigue, next appointment arrangement etc.		
Reflective Motivation	Unconvinced of health benefits of micro-breaks		
	Micro-breaks interrupt flow and are thus counter-productive		
	Concerned that other people will notice and negatively perceive break behaviours.		
	A technology that automatically tracks sitting, provides prompts/cues for breaks and visual feedback on my pattern would give people more confidence in improving my break pattern		
	Keeping a healthy work style is a low priority compared with work achievement.		
	Have thought about it but haven't informed a strong intention to improve work-break pattern		
	Taking micro-breaks is in conflict with professional standard/identity		

COM-B	Statements on office workers' barriers and facilitator to breaking up sitting with hourly micro-breaks in the workplace	To what extent does this reflect what you've observe in your workplace? (1-not at all, 5-very)	How important do you think this factor is in determining micro-break behaviour? (1-not at all, 5-very)
Automatic Motivation	Have habits, routines and ingrained behavioural patterns that contribute to regular breaks. (e.g. drinking water/tea, refilling vessel regularly)		
	Have habits, routines, ingrained patterns and obsession-compulsion that contribute to prolonged sitting behaviours (e.g. impulse to power through)		
	Breaks away from seat evoke positive affect		
	Feel guilty for taking breaks.		
	Less likely to take breaks when feeling stressed.		
Physical Opportunity	The organisation allows flexibility in how employees complete work and doesn't encourage presenteeism		
	Heavy workload and tight deadlines impel me to sit continuously for longer than I would love to		
	People have access to software/Apps/gadgets for prompting breaks (please give names in the last column)		
	Existing prompts/cues for breaks have limitations (please give reasons in the last column)		
Social Opp.	Co-workers invite each other to take micro-breaks together		
	Spontaneous chats by the side of a break facility (e.g. coffee machine) is common		
	social norm: most co-workers are good at taking regular micro-breaks and there is no pressure on sitting down to work		

Appendix 9: Group worksheet for the design workshop (Chapter 5)

Activity 3: Group Ideation

Use and user context: 1.

What's the user's job role, work activities?
What's the organisational culture?
What characterise the space and social relations of the workplace?

Behavioural target: 2.

who needs to do **what** differently, **where**, **when** and **how**

Key COM-B to target: 3.

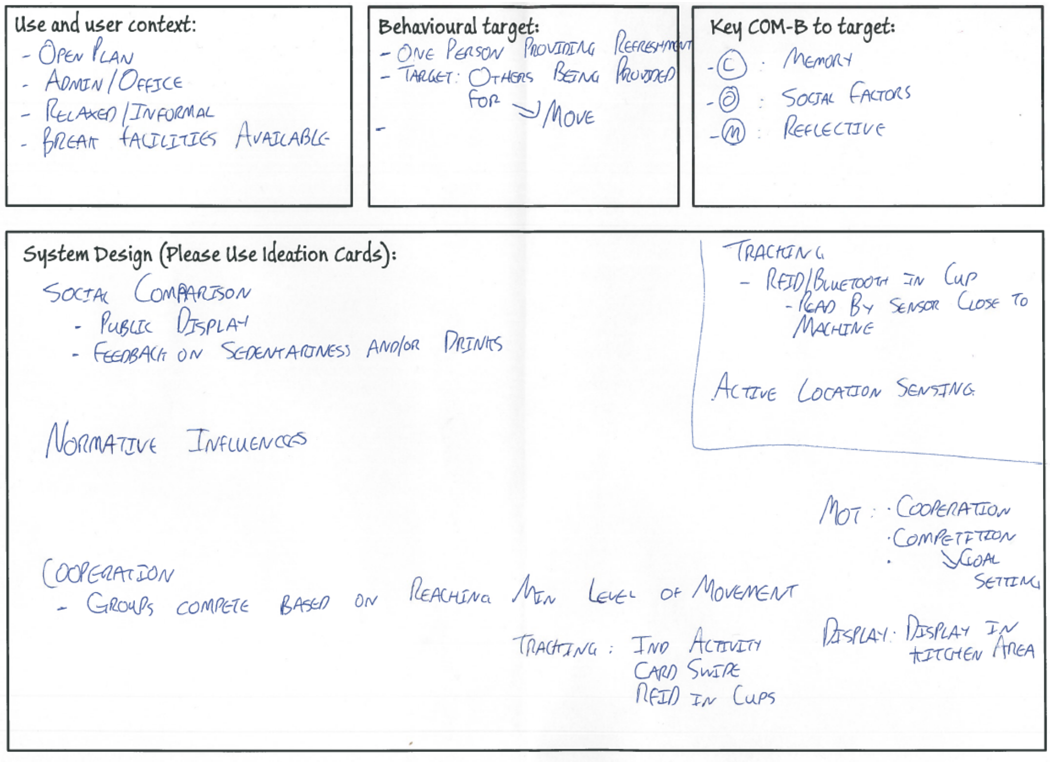
What need to change for the desired behaviour to occur?
Psychology/physical capability;
Physical/social opportunity;
Reflective/automatic motivation

System Features (Please Use Ideation Cards): 4.

Functional requirements:
How the system should behave to influence those constructs?

Non-functional requirements:
What (physical and social, tangible and intangible) qualities do you want your enchanted objects to have?

Appendix 10: Completed worksheet of Group 1 (Chapter 5)



Use and user context:
- Open Plan
- Admin / Office
- Relaxed / Informal
- Break Facilities Available

Behavioural target:
- One Person Providing Refreshment
- Target: Others Being Provided For ↘ Move
-

Key COM-B to target:
- (C) : Memory
- (O) : Social Factors
- (M) : Reflective

System Design (Please Use Ideation Cards):

Social Comparison
- Public Display
- Feedback on Sedentariness and/or Drinks

Normative Influences

Cooperation
- Groups compete based on Reaching Min Level of Movement

Tracking: Ind Activity
Card Swipe
RFID in Cups

Tracking
- RFID/Bluetooth in Cup
- Read by Sensor Close to Machine

Active Location Sensing

Mot: · Cooperation
· Competition
· ↘ Goal Setting

Display: Display in Kitchen Area

Cards used by Group 1

Cards used by Group 2

Appendix 11: *WorkMyWay* Functional Specification Document (Chapter 5)

grey shades represent those requirements not implemented in the end for technical and practical reasons

Background and motivation

Prolonged sitting at work has become a major health hazard for office workers. While it is unrealistic to entirely eliminate sedentary work from modern society, it is possible to minimize the adverse health impact of occupational sitting, for example, by interspersing sedentary time with very simple physical activities of light to moderate intensity, like standing up to get a cup of tea, which has found to alleviate the metabolic dysfunction caused by prolonged sitting. The proposed system is targeted at those office workers who normally have discretion over when to take minibreaks at work, but end up sitting for longer than they desire. A user study found a main contributing factor to be the lack of memory resources office workers have to keep track of time and break patterns at work. So the system design is aimed to **automate tracking of sedentary time and break frequency, remind users to take simple breaks** in the form of walking about or refilling up a mug **every 45 -55 minutes** and enhance user' self-reflection on work behaviours.

Overview of the system

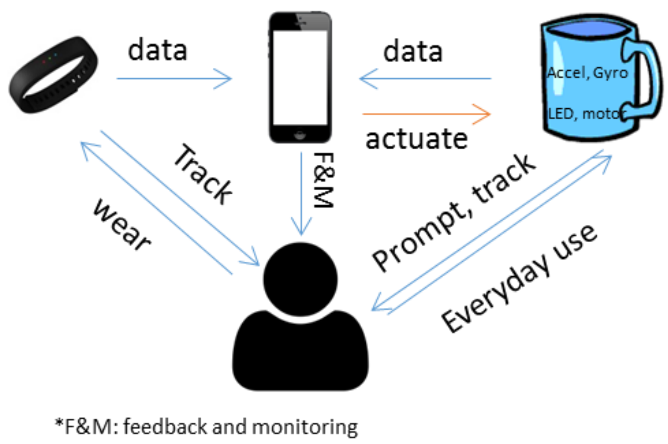


Figure 1 System Diagram

The system will consist of 3 components – a wearable activity tracker, a mug with attached computing and an iOS (or Android) App (Figure 1). Both the wearable activity tracker and the computing part attached to the mug will be built on the *MetaWear* RG platform, which is a tiny (26mm x 17mm x 2.5mm) development board with built-in accelerometer, gyroscope, temperature sensor, BLE connectivity, rechargeable battery and (optional) vibrating motor. The platform comes with iOS/Android SDK. Details on the development board can be found here https://store.mbientlab.com/product/*MetaWear*-rg/.

Core functions (implement first)

Interaction Functions:

- The wearable activity tracker should keep track of the current sedentary period and constantly upload this "sedentary time" to the smartphone App via Bluetooth Low Energy (BLE).
  - The *MetaWear* API/SDK has included step detection and motion event triggers on both iOS and Android (https://mbientlab.com/iosdocs/latest/accelerometerbmi160.html#notify-when-placed-flat) (https://mbientlab.com/androiddocs/latest/bmi160_accelerometer.html#step-detection). Thus for ease of development, sedentary time can be operationalised as period of no steps in this app. So we only need to have a variable that stores the duration of the current sedentary episode (ie. time since the last step was detected); once step patterns are detected using the provided "Notify on Step" event handler, the current sedentary period should be reset to 0 min and the motion tracker should start recording step numbers. (alternative algorithm was implemented see Section 5.4.3.3)
  - Some structured testing and recording may need to be carried out by the lead researcher in collaboration with the developer to validate the *MetaWear* step detection algorithm/logic.
- The App actuates the LED and vibrating motor attached to the mug via BLE based on the following rules:
  1. If sedentary period $\in$ (45, 55) (unit: minutes), then turn on a yellow light, representing the message that "You can consider a break now!"
  2. If sedentary period $\in$ [55, 59) (unit: minutes), then the light turns to green, meaning "You should take a break now!"
  3. If sedentary period > = 59 min, then flash a green light, meaning "You are reaching the end of the time window to get score. Take a break now!"
  4. If the reminder is on && the user tapped on the *MetaWear* board attached to the mug, the reminder will be turned off for 10 minutes (ie. "Snooze"). But snoozing won't affect the sedentary time record or reminders scheduled in the system for the next stage; only after 3 snoozes will scheduled reminders be cancelled.

5. If during the reminder period, step patterns are detected from the Wearable *MetaWear*, the App will turn the light into a green breathing light for about 3 seconds to acknowledge that the break has been detected and that sedentary time has been reset.

- The App should feed the data back to the user in the form of an activity timeline as well as numeric summary:
    a. Daily inactive minutes: xx minutes (the sum of sitting longer than 60 min)
    b. Longest episode of inactivity: XX minutes
    c. Types of data collected and visualised will be detailed in the next section

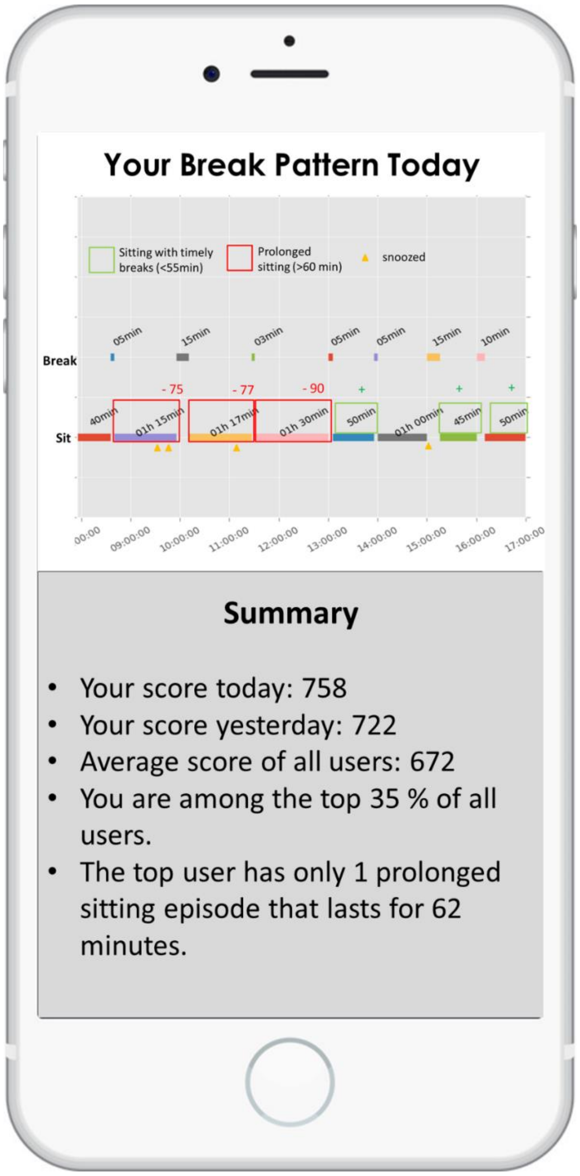


Figure 2 Example App UI for data feedback

<u>**Data Sync and Storage:**</u>

- When a step is notified, ideally the *MetaWear* should cache **step number** locally, in case the user didn't take the phone with him/her, and upload to the App once connection is available again (the *MetaWear* turned out not to work like this as the manufacturer claimed). The *MetaWear* board has the storage for 10K – 15K 4byte sensor entries with timestamp, which, in theory, is more than sufficient for storing step number during a micro-break. The *MetaWear* API has provided a logging class for accessing the on-board flash memory (https://mbientlab.com/androiddocs/latest/logging.html).
- The App should be able to store the above behavioural data about the user for at least 12 hours locally on the phone:
    - The **start/end times and duration of each sedentary episode**; the **start/end times and duration of each break**, and **number of steps taken in each break**; "timestamped" snooze record.
- There should be a scheduled time on each day for the App to upload all data to a database server, where data will be stored over the study period (>=4 weeks). There should also be a "sync" button in the App so that the user can manually initiate synchronisation any time. (it was set to automatically synced in near real time)

Research administration:

- The researcher can access, query and download data from the server with password login.
- The researcher should be able to tweak parameters such as the sedentary time threshold for triggering the reminder, the modality of the reminder (whether vibrates or not, and choose light colour) etc.

Add-on functions (requirements will be discussed and finalised between the researcher and the developer)

- There can be a function for the user to set break reminder interval. But this function can be disabled and made invisible to the user by the researcher.
- The *MetaWear* board attached to the mug can capture and upload raw data about the mug's movements to the App. An algorithm needs to be implemented in the App to determine if a movement pattern constitutes a drinking event or not, potentially by comparing the tilt angle to a threshold that is adapted to the estimated amount left in the mug. (could not implement this because of difficulty with streaming accelerometer axial data)
    - If a drink event is detected, the App will actuate a breathing blue light on the *MetaWear* attached to the mug to acknowledge that "This drinking event is recorded".
    - If the user has not drunk from the mug for 30 minutes, the App will turn on the LED light on the mug into blue to indicate "you need to keep hydrated".

- When the user starts walking (ie. App notified of step by the wearable board), the App should pause drink detection on the mug (to avoid mistaking steps for drinking) and trigger step detection on both boards.
- Similar to the above, step numbers captured by both boards should be cached in the on-board flash memory during the micro-break and upload to the phone when re-connected, just in case the user takes the mug but leaves the phone behind. After receiving timestamped step counts from both boards, the App should then have a function that decides if the user has taken the mug with him/her based on the similarity/difference between two step patterns. If similar, then this can be assumed as a "refill" event. Temperature sensor data may be utilised to increase the accuracy.(water break event was simply operationalised as high intensity movement of the cup device detected, see section 6.3.4.8)
- The App records the timestamps for both of the above events and uploads such records to the database. As illustrated in Figure 3. the user can choose to make them visible on the timeline.
    - This is to demonstrate that a mug with embedded sensing can make mundane micro-breaks somehow accountable and more memorable, as it puts the wearable physical activity data into context. This has value to both the researcher who wants to understand the mechanism of behaviour change and the group of users who just fancy the idea of quantified self and technology-mediated reflection. Thus this function should be configurable by the user (ie. technology probe) so as to probe into how users interpret and utilise data captured by everyday objects.

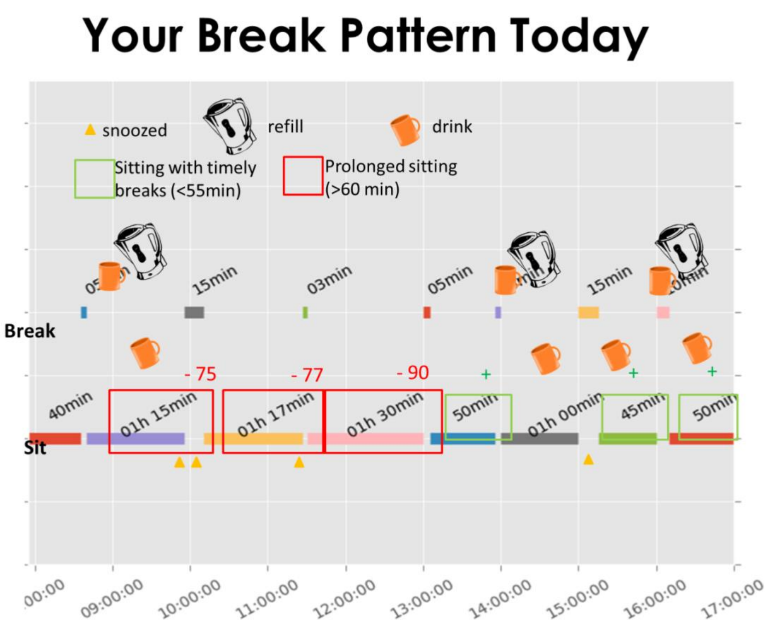
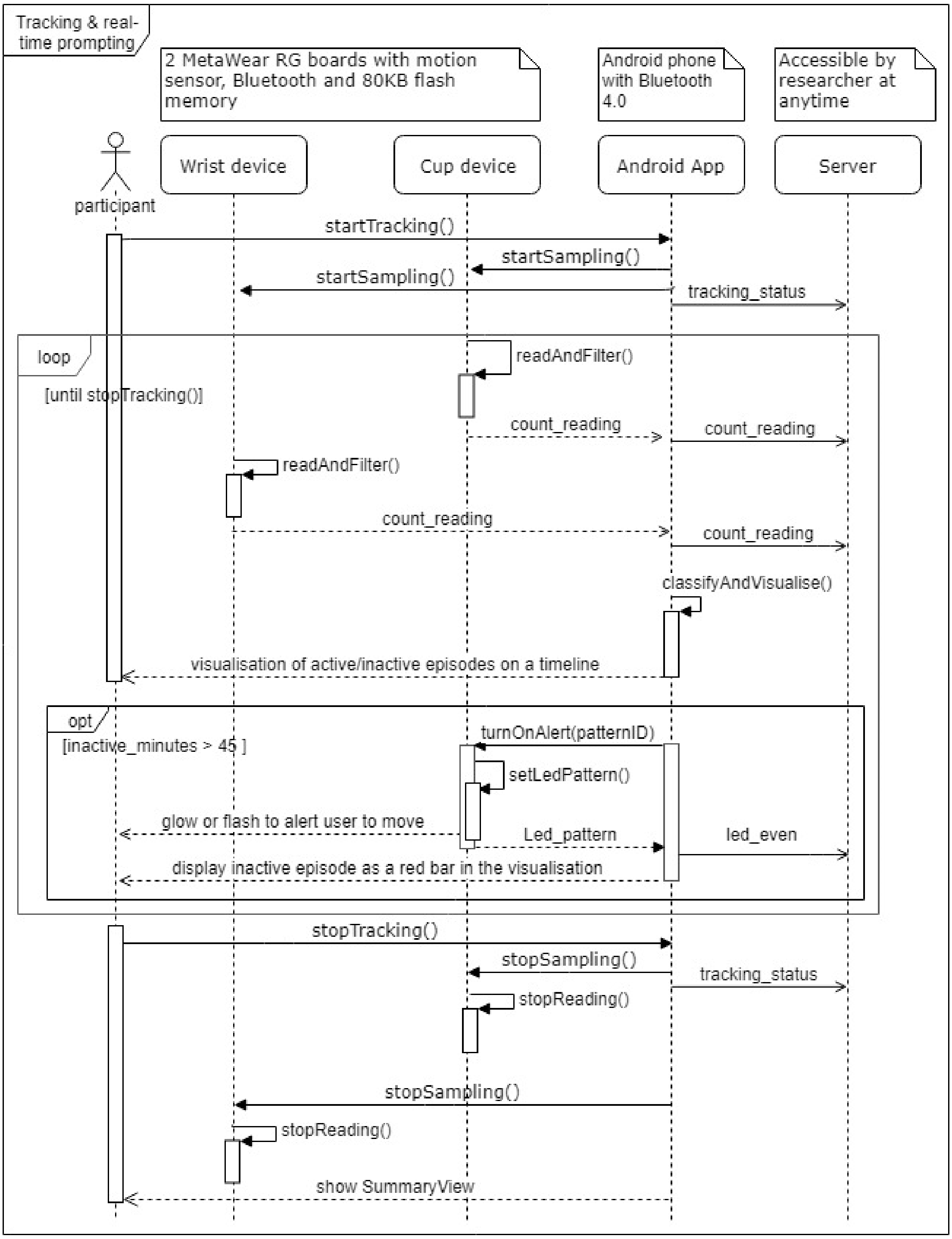


Figure 3 data feedback with add-on functions

Appendix 12 Sequence of interactions between different system components (Chapter 5)



Appendix 13: Casing design (Chapter 5)

	Pros	**Cons**
 #1: specific bottle + 3D printed screw cap	• Sensor becomes an integral part of the cup, neat design • Easy and economical to produce with MRL facilities • Able to obtain (proxy) measures of drinking behaviours based on number of times cap is taken off • Generally waterproof for day-to-day use	• Not FDA certified food safe (sealing device); manufacturer advice • May use food grade silicone coating, but 1 mm inaccuracy at least • Compatible with particular bottles • Unappealing to hot beverage drinkers (study likely to be in winter) • Has to screw out the electronic part for charging
 #2: the above bottle + 3D printed screw bottom	• Isolated from drink; no need to meet food safety standard • Easy to produce with MRL facilities • Generally waterproof	• May not detect drinking behaviours (false negative) • Mediocre design • Compatible with particular bottles • Unappealing to hot beverage drinkers (study likely to be in winter) • Because of the mouthpiece design, need a new bottle for each participant (6 GBP X 20)
	• Isolated from drink; no need to meet food safety standard	• There is the chance that LED is not facing the user • As the charging port is expose and thus not waterproof, has to be taken off while cleaning; after

 #3: Case attached to any bottle/cup with Velcro or elastic band	• Easy and economical to produce • **<u>Flexible:</u>** can be used with user's own mug/cup; • More appealing to hot beverage drinkers; • Able to obtain (proxy) measures of drinking behaviours based on tilt • No need to take it off for charging	wash, user may forget to stick the unit back;
 #4: Porcelain (3D print mould ➔ ceramic powder)	• Suitable for hot beverage drinkers; • Able to obtain (proxy) measures of drinking behaviours based on tilt • More creative space • Can be waterproof	• need significant expert design efforts • Need to design for waterproof • 1 – 3 mm firing shrinkage • high manufacturing cost: $15.00 per part + $0.13 per surface area cm2 X 516cm2 = $82 = £63
 #5: use the casing of an existing smart thermos	• Food safe and heat resistant; • Waterproof; • Good for keeping drinks cool or hot;	• Not good if the user wants hot beverage to cool down naturally; • Need to solder an LED to the board and fix the LED underneath the heart shape, making it difficult to take the board out for charging (may snap the wire) • Adding wireless charging feature would increase the cost • There is the chance that LED is not facing the user

Common cons: #1,#2,#5: waterproof means the charging port is hidden and that the electronics need to be removed for charging. As a result, the user may forget to put it back after charging.

Appendix 14: *WorkMyWay* – "about" screen (Chapter 5)

WorkMyWay

About

Scientific facts:

Prolonged sitting is associated with an increased risk of cardiovascular disease (14%), type 2 diabetes (91.0%), cancer mortality (13%), and all-cause mortality (22%), independent of physical activity levels, as found in a recent systematic review [1].

Sitting for long periods can slow the metabolism, which affects the body's ability to regulate blood sugar, blood pressure and break down body fat. The UK Department of Health < [2] strongly recommends adults reducing total sedentary time and breaking up extended periods of sitting. Indeed, regular breaks in sedentary behaviour are associated with a healthier metabolic profile, as even simple activity like walking to a tea room to refill bottles/cups can alleviate the metabolic dysfunction caused by long periods of inactivity.

Limitations with current research:

Several recommendations exist in regard to what counts as a healthy sit-break pattern, ranging from "1 to 3 minutes of light physical activity break in every 30 minutes of sitting" to "5-minute break in every 60 minutes of sitting".

How can the App help you:

Our system, namely WorkMyWay, adopts a pragmatic target of "break every 60 minutes" as the default, which you can adjust to your own needs in setting. If you wear the wristband and press 'start tracking', the system will automatically monitor your period of inactivity and prompt you subtly with an LED light.

WorkMyWay also supports retrospection and self-reflection by presenting graphic and numeric feedback on your daily activity. It labels sitting episodes that are longer than 60 minutes as "prolonged sitting". Sitting episodes <= 60 minutes are labelled as "healthy work", as the focus here is to kick start a more regular break pattern, though you should be aware that a reduction in total sitting can also be beneficial.

Tips:

Every small break counts. There are many simple tasks you can do in the workplace to increase incidental walking without comprising productivity, such as collecting printouts, walking to colleagues rather than using emails/telephone, keeping hydrated and not postponing toilet breaks.

We suggest attaching the LED reminder to a bottle or cup because hydration is also an important aspect of workplace health and wellbeing. Whenever you get prompted but cannot think of a sensible break activity, you can always take your bottle/cup to a water cooler or something.

Declaration:

This system was designed by Yitong Huang as part of her PhD research, supervised by Prof. Steve Benford (Computer Science) and Dr. Holly Blake (Health Sciences), at the University of Nottingham. By using the App and connected devices, you consent to having your physical activity data and within-App usage data collected and used for research purposes. For any inquiries please contact: Yitong Huang (yitong.huang@nottingham.ac.uk).

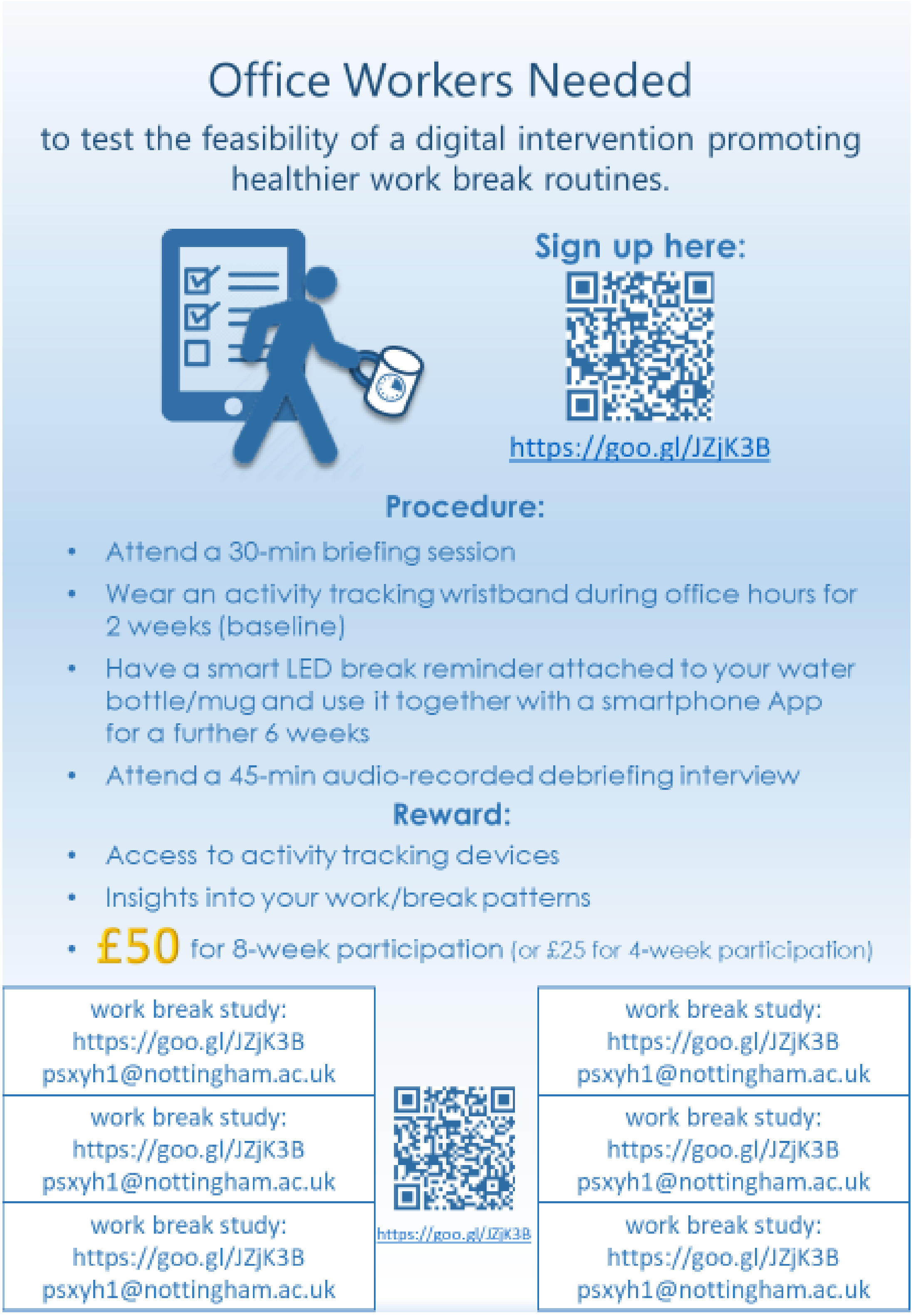
Acknowledgement

The researcher is supported by Horizon Centre for Doctoral Training at the University of Nottingham (RCUK Grant No. EP/L015463/1) and Unilever UK Ltd. Special thanks to Dominic Price for dedicating his time to developing and maintaining the system.

[1] *Biswas A, Oh PI, Faulkner GE, Bajaj RR, Silver MA, Mitchell MS, et al. Sedentary time and its association with risk for disease incidence, mortality and hospitalization in adults: a systematic review and meta-analysis. Ann Intern Med2015;162;123-32.*

[2] *Department of Health, Physical Activity, Health Improvement and Protection, "Start Active, Stay Active," 2011. [Online]. Available: https://www.gov.uk/government/uploads/system/uploads/attachi [Accessed 4 May 2017].*

Appendix 15: Promotional material for the feasibility study (Chapter 6)



Appendix 16: On-line sign-up form and screening questionnaire (Chapter 6)

Feasibility study of a digital work break intervention

Please note: due to overwhelming popularity and limited number of devices, newly signed up office workers will be contacted after Jan. 2018 to schedule a briefing session. Thanks for your patience!

Please complete this form if you would like to participate in a research study that will involve a 30-min briefing session, 8-week use of a break tracking and reminder system during work hours, and a 45-min debriefing interview. Answers to those questions are used to check your eligibility and schedule the initial briefing session with you. You will be compensated with a £50 Amazon voucher upon completion of the whole study. For inquiries, please contact yitong.huang@nottingham.ac.uk.

Are you currently employed on a desk-based job that involves a significant amount of sitting on most days?

Yes	No

Do you have the freedom in your workplace to take regular mini-breaks/comfort breaks if you want to?

Never	Rarely	About half the time	More often than not	Always

Do you have any physical disability that limits your ability to move around in office?

Yes	No	Do not wish to disclose

>>

Feasibility study of a digital work break intervention

Full name:

Contact details (email and/or phone):

Please briefly describe your job (both the type of industry/organisation and your job role/title):

How many hours did you work in the past 7 days?

During the past 7 days, how many days were you at work?

How would you describe your typical work day in the last 7 days? (This involves only your work day, and does not include travel to and from work, or what you did in your leisure time). Make sure it adds up to 100%

sitting	0
standing	0
walking	0
heavy labour or physically demanding tasks	0
Total	0

The researcher would like to visit your workplace to do the 30-min briefing. Please provide your office address and convenient times (could be lunch time or after work hours):

office address

preferred time slots:

If you use an Android smartphone onto which you are happy to install an study App, please specify the brand and version name (e.g. Galaxy S4, Nexus 5). This will help shorten your waiting time and save research budget. Thanks!

>>

Appendix 17: Feasibility study - Participant Information Sheet and consent form (Chapter 6)

Information sheet:

Please take your time and read both the information sheet and consent form carefully before signing. Please retain one copy of this document for your own use. You are encouraged to ask the researcher questions, if anything is unclear.

This study is aimed to evaluate the feasibility of a novel mode of delivering sedentary behaviour interventions to healthy office workers during work hours. The technology only collects data on your physical activity and break habits, but not data relating to any other aspect of your job. No identifiable information about you will be provided to your employer.

This briefing will last approximately 15 minutes. You will complete some questions about yourself, your usual break activities, and factors related to your break patterns at work. Then you will be given an Android smartphone with the study App installed and an activity tracking wristband.

At the beginning of the study, we will need to assess your sitting behaviour before receiving any interventions. You will need to wear the wristband and use the smartphone as data acquisition devices during office hours while maintaining your normal physical activity level in Week 1 -2.

At the end of Week 2, the researcher will come to see you again. Please bring a cup or bottle you use most in the office to have a smart LED break reminder fixed to the surface. The researcher will also install a new version of the App on the study phone and give you feedback on your sitting behaviour pattern during baseline week.

The feedback will help you set up personal goals and customize the App setting (detailed instructions will be given then).

For Week 3 – Week 8, you will be using the system (the wristband, the App and the cup/bottle with smart LED) on your own. The smart LED will remind you to take breaks based on the minutes of inactivity monitored by your wristband in real time; in addition, you can review how your break pattern has changed over time in the App and set personal goals.

At the end of Week 8, you will attend a 45-min debriefing interview at a time convenient for you. We will discuss your experience of the technology and study, which will be audio recorded. A £50 Amazon voucher will be emailed to you after the interview to compensate for your time and feedback. You will need to return the research devices. Please keep the study devices and data safe during the study period, just like you would do to your other digital devices and data.

All data transferred to the researcher will be securely stored on the University server only accessible by the researchers involved in the study, in accordance with the Data Protection Act 1998. Your data will be analysed and written up in research publications by the researcher. All data reported in publications will be made anonymised. Any information about you will be described under a pseudonym.

Your participation in this research is entirely voluntary. You may withdraw your consent at any time by contacting the researcher and ask your data collected by that point to be deleted and excluded from the study. During the study, if there is any period in which you don’t want your physical movements to be recorded, simply remove the wristband for the period and put it back on afterwards. If you decide to discontinue using the system halfway through the study (ie. after Week 3), but would still like to contribute your data collected in the previous 3 weeks to research and attend a debriefing interview, you can still receive a £25 Amazon voucher.

This study has been approved by the Computer Science Ethics Committee (CREC) of the University of Nottingham. The researcher is supported by Horizon Centre for Doctoral Training at the University of Nottingham (RCUK Grant No. EP/L015463/1) and Unilever UK Ltd.

For any inquiries please contact: Yitong Huang (Tel: +44 (0) 7821475752, Email: yitong.huang@nottingham.ac.uk, School of Computer Science, The University of Nottingham, Wollaton Road, Nottingham, NG8 1BB)

Participant Consent Form

This is to confirm that I have agreed to take part in a research study conducted by Yitong Huang. I have read the information sheet provided and I understand what is involved.

I freely give my consent to take part in this study. I am a consenting adult over 18 years old and have no disability or health condition that precludes physical movements. I understand that I have the right to withdraw from the study at any time by contacting the researcher without giving a reason.

I understand that by wearing the wristband and using the App, I consent to sharing data about my physical activity and interactions within the App with the researcher.

I understand that my data collected in this study will be stored under the Data Protection Act 1998 and be used anonymously in publication. I have the right to ask for my data to be removed from potential publication submission up to the point of study write up, although once it is published it can no longer be removed.

Please read the following statements below and select your response by ticking the appropriate boxes:

YES ☐ NO ☐	I have received a smartphone on loan for this period. I undertake to ensure that this is kept safely and securely and to return it in good condition at the end of the study.
YES ☐ NO ☐	I understand that the App together with the connected devices will collect data about my physical activity, cup movement and within-App interactions and upload them to the university server.

YES ☐ I consent to my debriefing interview being audio recorded and
NO ☐ transcribed.

YES ☐ I consent to my questionnaire, interview and App data being
NO ☐ analysed and reported anonymously in publications and presentations.

YES ☐ I consent to my interview quotations, sitting pattern and App
NO ☐ activity history being referred to in publications anonymously.

YES ☐ I am confident that the appropriate management approval, if
NO ☐ any is required, is in place for me to contribute time and take part in the study in the workplace.

Signature of Participant: .... Date: ....

Print Name of Participant: ....

I have explained the study to the above participant and he/she has agreed to take part.

Signature of Researcher: .... Date: ....

Appendix 18: Pre- and post-intervention questionnaire for the feasibility study (Chapter 6)

Participants ID:_______

Part I. Occupational sitting and physical activity questionnaire (OSPAQ)

How many hours did you work in the past 7 days? ____________

During the past 7 days, how many days were you at work? __________

How would you describe your typical work day in the last 7 days? (This involves only your work day, and does not include travel to and from work, or what you did in your leisure time). Make sure it adds up to 100%

a. Sitting ______%

b. Standing ______%

c. Walking ______%

d. Heavy labour or physically demanding tasks ______%

Part II. Work Fatigue Inventory

Many people experience a sense of extreme or excessive tiredness during and at the end of the work day. This excessive sense of tiredness is called fatigue and can involve one's physical, mental, and emotional resources. The questions below begin by asking about your experience of physical fatigue, followed by your experience of mental fatigue and emotional fatigue. For each question, check the box that most accurately reflects how often you experience each aspect of fatigue.					
Physical fatigue involves extreme physical tiredness and an inability to engage in physical activity. During the PAST 30 DAYS, how often did you …	Never	Occasionally	About half of the time	More often than not	Everyday
1. feel physically exhausted at the end of the workday?	○	○	○	○	○
2. have difficulty engaging in physical activity at the end of the workday?	○	○	○	○	○
3. feel physically worn out at the end of the workday?	○	○	○	○	○
4. want to physically shut down at the end of the workday?	○	○	○	○	○
5. feel physically drained at the end of the workday?	○	○	○	○	○
6. want to avoid anything that took too much physical energy at the end of the workday?	○	○	○	○	○
Mental fatigue involves extreme mental tiredness and an inability to think or concentrate. During the PAST 30 DAYS, how often did you …	Never	Occasionally	About half of the time	More often than not	Everday

7. feel mentally exhausted at the end of the workday?	○	○	○	○	○
8. have difficulty thinking and concentrating at the end of the workday?	○	○	○	○	○
9. feel mentally worn out at the end of the workday?	○	○	○	○	○
10. want to mentally shut down at the end of the workday?	○	○	○	○	○
11. feel mentally drained at the end of the workday?	○	○	○	○	○
12. want to avoid anything that took too much mental energy at the end of the workday?	○	○	○	○	○
Emotional fatigue involves extreme emotional tiredness and an inability to feel or show emotions. During the PAST 30 DAYS, how often did you	Never	Occasionally	About half of the time	More often than not	Everyday
13. feel emotionally exhausted at the end of the workday?	○	○	○	○	○
14. have difficulty showing and dealing with emotions at the end of the workday?	○	○	○	○	○
15. feel emotionally worn out at the end of the workday?	○	○	○	○	○
16. want to emotionally shut down at the end of the workday?	○	○	○	○	○
17. feel emotionally drained at the end of the workday?	○	○	○	○	○
18. want to avoid anything that took too much emotional energy at the end of the workday?	○	○	○	○	○

Part III. Determinants of micro-breaks

Note: the presentation here groups questions based on psychological constructs measured; the questions presented to participants were in the order indicated by the item number)

#regularly: every hour or more frequently

break: any interruption in sitting, which might be work-related activity

prolonged sitting: sitting episodes >=60 min

-: strength of factor negatively contributes to micro-break behaviours, and hence negatively coded in data

*: appearing in post-study questionnaire only

Please Indicate the extent to which you agree with the following the following statements

(1 strongly disagree – 7 strongly agree or slider)

<u>Strength of intention:</u>

20. I intend to break up sitting with regular micro-breaks throughout the day.

Beliefs about consequences (outcome expectancy):

21. For me to a workday with regular# micro-breaks is pleasant
22. For me to a workday with regular micro-breaks is productive
23. For me to taking regular micro-breaks at work is healthy

Beliefs about capabilities (perceived behavioural control, self-efficacy):

24. All things considered, if I wanted to I could take regular breaks at work

Resources, facilitating conditions, barriers:

Perceived barrier 1: heavy workload

25. (-)Heavy workload and tight deadlines impel me to sit and work continuously longer than I would like to

Perceived barrier 2: organisational culture discouraging breaks

27. (-)The organisational culture and climate here discourages regular breaks and I feel I'm being watched

Perceived facilitator: organisational culture encouraging flexibility and regular breaks

26. The organisational culture and climate here allows flexibility in how I complete work and is supportive of regular micro-break behaviours.

Memory:

29. (-)I find it difficult to keep track of time when engrossed in work (*, when *WorkMyWay* functions properly)

30. (*Provided that *WorkMyWay* functions properly,) At the end of each day, I have an idea of how much time I've spent in prolonged sitting

31. (*Provided that *WorkMyWay* functions properly,) At the end of each day, I have an idea of how often I have taken breaks

Need for prompts/cues:

32. (-)To take regular breaks, I need better prompts/cues to remind me to stand up when I've been sat for too long.

Perceived difficulty of prospective memory task: 29,32

Perceived ease of retrospective memory of break patterns: 30,31

Break habit (Self-Report Behavioural Automaticity Index, SRBAI)

28. Taking micro-breaks throughout workdays is something I do automatically

33. Taking micro-breaks throughout workdays is something I start doing before I realize I am doing it

34. Taking regular micro-breaks throughout workdays is something I do without thinking

35. Taking micro-breaks throughout workdays is something I do without having to consciously remember

Automaticity of "taking a micro-break in response to the LED prompts):

36. Taking a micro-break whenever the LED is glowing is something

1) I do automatically

2) I do without having to consciously remember

3) I do without thinking

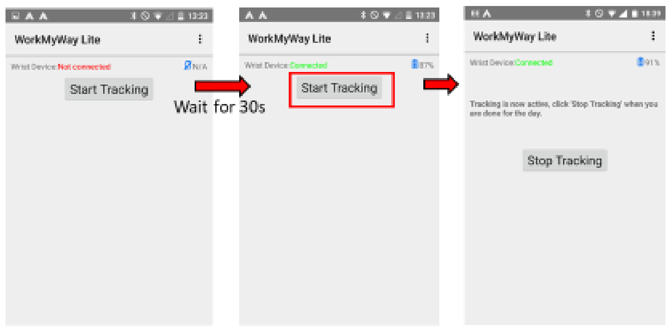
4) I start doing before I realize I am doing it

Appendix 19: Participant “cheat sheet” for baseline weeks (Chapter 6)

WorkMyWay Study To-do’s

Start a workday

1) Kill the App process *(see overleaf for illustration)*
2) Turn Bluetooth off
3) Turn Bluetooth back on
4) Relaunch the App and wait for 30 seconds, it changes from ‘disconnected’ to connected,
5) Press ‘Start Tracking’



During the workday

- Maintain your normal behavior this week;
- Take the phone with you if you expect to be outside the room for > 15 min;
- If you are temporarily away, it’s fine to leave the phone. But upon your return, kindly open the App. It usually takes 15 seconds for it to auto-reconnect; but if auto-reconnection does not happen, perform 1) – 4) above.

Before finishing the day

- Press ‘Stop Tracking’

FAQ

How to kill the App Process?

1. Press on the square button at the bottom of the screen to launch the recent application menu
2. Find ‘WorkMyWay’ from the list
3. Tap, hold and swipe it to the right.

What do the LED flashes mean?

Blue:
getting disconnected

Purple:
getting reconnected

How to charge the wrist device?

- Take the board out of the wristband and connect it to the charging station. Put it back once after charging.

How often should I charge the devices?

1. Charge the wrist device for at least 2 hours for every 2 days of use; also charge it whenever the battery level is < 50%
2. Charge the phone at your convenience; just not let it die.

What if the tech is not working properly?

If you keep receiving error messages saying ‘no data for extended period’ or encounter any other tech problem, the researcher is ready to help you ☺. Here is her contact: yitong.huang@nottingham.ac.uk / 07821475752
Room B06, Computer Science, NG8 1BB

Appendix 20: Motivational interview/brief action planning protocol (Chapter 6)

Opening

How has the first two weeks been for you? Did the act of wearing a device change your behaviour pattern in anyway?

Reflection

Shall we look at your data together?

Feedback on behaviour

So what do you think of your current amount of sitting every day?

Goal setting

We've been talking about prolonged sitting and health, is there anything you would like to do for your health in the workplace in the next week or two?

If have an idea

E.g. every hour; every 90 min

If Not sure:

- Would it be OK if I shared with you some candidate end states you might want to achieve?

Show work styles:

Which of them is closer to your ideal?

Which of them reflects what you plan to achieve by the end of the study?

Perhaps you can compare your graph against the preferred style, see if there is something you would like to work on?

Introduce the App

That sounds like a great place to start with

The way the App works is like this: your wrist device sends data to the phone, then it will classify and …trigger up to 3 reminders…

Behavioural planning 1

Explain potential tech problem → Is it okay if I share with you some coping strategies/tactics other participants I've worked with have used?

- Two participants use the system in a gamified way, as they say, they will **try to 'beat it' before it light up.**
- Whenever they go for a break, they would also open the App to check the time is still fine, just for reassurance.

- By launching the App, they also make sure their break is registered. i.e. they use the tech system as a break 'check-in' tool.

Behavioural planning 2

Do you expect a lot of variety in your work that will influence how often you can and want to take breaks?

- If yes, people usually find it helpful to be really specific about their action plans in different contexts. Do you want to set some 'if-then' rules for different social contexts, working tasks and potentially days with deadlines?

Commitment statement

- Just make sure that I understand your plan, can you please repeat back what you've decided to do?
- While [task: working alone/meeting/working on a deadline]....
    - I will take a break before it reaches... minutes

Scaling for motivation

On a scale of 0 to 10, how motivated are you to complete the plan?

If <5, actually that is a lot better than a 0. Don't worry. You can give it a go first.
Or perhaps you can use it purely as a reflection tool to compare your break patterns between days and see how they impact your productivity, mood and physical health.

Scaling for confidence

On a scale of 0 to 10, how confident are you in completing the plan?

Problem solving for low confidence:

What are the foreseeable difficulties for achieving this goal?

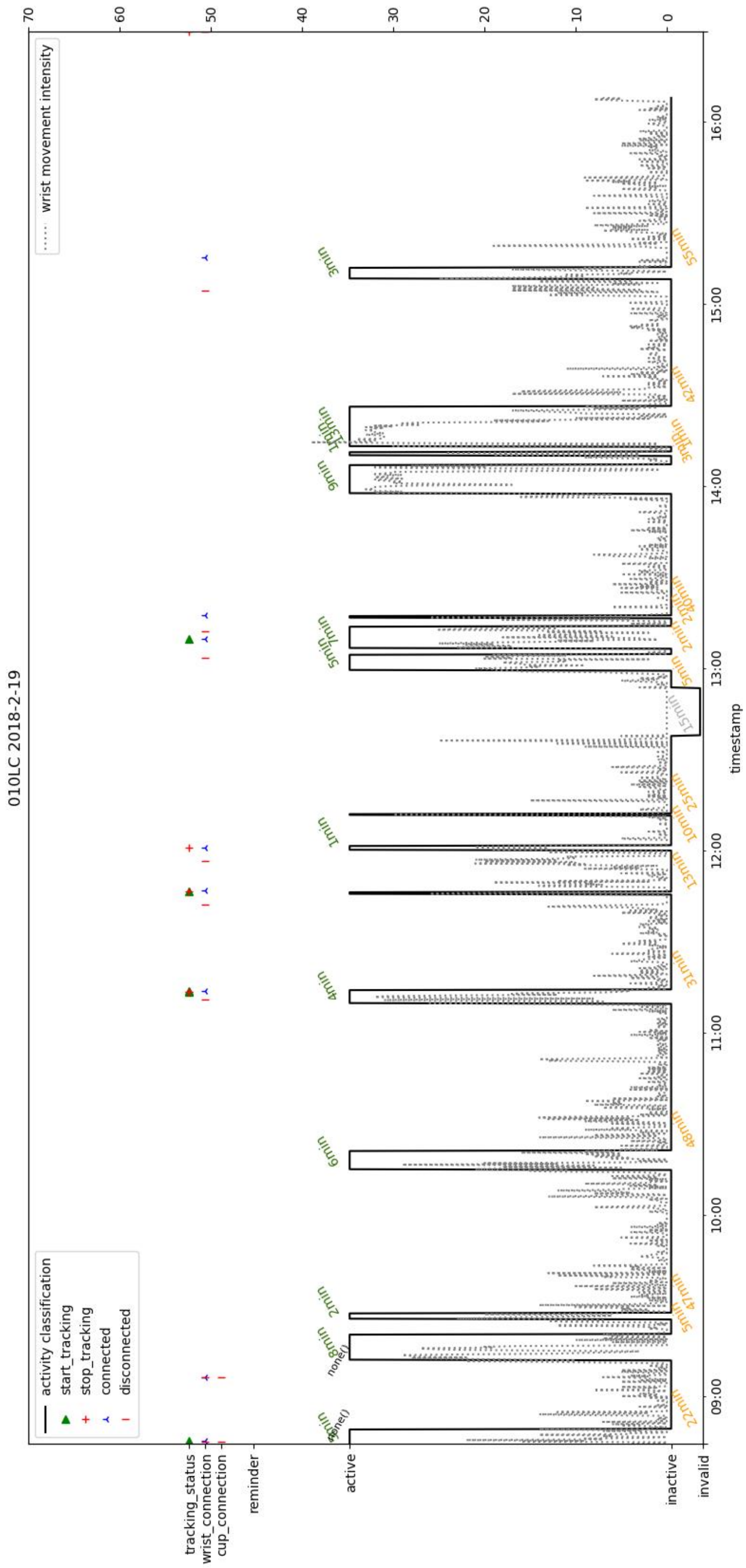
- *Discuss tactics:*

Arranging accountability

- Would you like to set a specific time to check about your plan to see how things are going? – in 2 weeks

Appendix 21: Examples of feedback on baseline behaviour provided to participants at the action planning session (Chapter 6)

user_id	date	day	Turn_O	first_re	Turn_O	last_re	daily inva	daily va	daily ac	daily in	total pr	total su	prolong	longest
50	13/02/2018	0	09:39:50	07:46:45	16:31:25	16:31:45	0 days 01:02:	07:42:30	01:50:45	05:51:45	02:06:00	04:37:30	1	02:06:00
50	14/02/2018	1	08:53:36	08:53:30	13:01:46	17:02:30	0 days 00:29:	07:39:30	01:27:30	06:12:00	05:09:30	05:50:15	4	01:30:00
50	15/02/2018	2	08:47:23	08:19:45	15:04:04	15:24:45		07:05:00	01:12:15	05:52:45	02:52:00	04:09:45	2	01:30:15
50	19/02/2018	3	08:45:17	08:44:30	16:29:40	16:08:15	0 days 00:15:	07:08:00	01:10:15	05:57:45		04:25:15	0	00:55:45
50	20/02/2018	4	08:42:54	08:42:00	16:17:31	16:26:30		07:44:30	00:45:30	06:59:00	05:18:00	06:06:45	4	01:34:30
50	21/02/2018	5	08:39:19	08:38:00	15:35:22	16:21:15		07:43:15	00:45:15	06:58:00	03:08:45	06:06:45	2	01:37:15
50	22/02/2018	6	13:08:19	08:40:45	16:24:35	16:24:45		07:44:00	01:17:15	06:26:45	04:12:15	05:12:00	3	01:38:45



Appendix 22: Debriefing interview questioning route (Chapter 6)

Implementation: study motivation & experience

Can you start by telling me how you became interested in the study in the first place?

How would you describe your experience of taking part in the study [I]?

- What do you think of the overall **length** of the study?
- Were you provided with enough **instructions** on what you needed to do?

Process of change

Did you notice any change in your behaviour or attitude over the course of the study? [M]

[Present objective data illustrating the change to facilitate discussion]

- Why not: Barriers→ tech problem? Work load? Social?
- Why: Facilitators → useful components

Technology experience

Can you list features that found most useful?

- From top of the list: how did you make use of it? [M]

Can you list features that found least useful?

- Why? How could it be improved?

➢ Tracking and prompting
  - Did you use the tracking function whenever you were at work?
  - How easy or difficult did you find it to integrate and embed the **tech use** into everyday **routines?** [C]
    - Sideway: impact on work; social barriers/facilitators
  - Was it accurate in telling if you are moving or inactive?
  - Was the reminder always placed within the field of your view [I]
  - On average how many prompts do you notice on a day [I] ?
  - How did you normally respond to the reminders [M] ?

➢ Data feedback:
  - Did you review the history? When and how? [I] [M]
  - Was the feedback accurate/meaningful/actionable/credible?
  - Which form of feedback did you look at most? [M]

➢ Goal setting:
  - How did you find the goal setting function? How often did you review and update it?

➢ 'About' page:

- Have ever read the page in the App that describes research on prolonged sitting and guidelines on how often people should take breaks? [I] [M]

Did you have any problems finding your way around the App? [C]

Contextual barriers:

Embed it into everyday routine: have you had to make any **adjustments** in your day-to-day life as a result of being part of the study?

Did it cause any **inconvenience**?

If mention 'social', then

Social influences **[C][I]:** Did your co-workers notice and talk about WorkMyWay?

- How do you think they viewed it?
- Do their opinions matter to you?

Do you think the culture in your workplace would encourage or discourage the implementation of WokrMyWay?

Without naming anyone, can you think of anyone who could have potentially benefited from the intervention? What could have been done better to engage them? [reach and uptake]

If mention 'annoying', then

Can you tell me other situations where (you found it disruptive?)

General

Could you identify any barriers to using WorkMyWay?

Do you have any suggestions as to how the study and tech could be improved?

Could you identify any barriers to regular breaks that haven't been addressed by WorkMyWay?

Do you have recommendations for improving the behaviour change aspect?

Is there anything you would like to add?

Appendix 23: Participants' profiles (Chapter 6)

pID	A_T	Q_T	D_VU	_CUP	D_P	R_L (mean, (min, max))	C
1	21(70.0%)	15(71.4%)	50.0%	13(43.3%)	1.6	35.5 (4.8,130.3)	38.2%
2	21(70.0%)	14(66.7%)	46.7%	10(33.3%)	1.4	80.4 (0.5,290.5)	20.0%
3	28(93.3%)	20(71.4%)	66.7%	13(43.3%)	4.1	65.8 (0.1,406.1)	36.2%
4	28(93.3%)	23(82.1%)	76.7%	16(53.3%)	2.8	24.8 (0.4,104.3)	41.8%
5	26(86.7%)	16(61.5%)	53.3%	4(13.3%)	0.6	89.3 (1.4,409.6)	46.7%
6	28(93.3%)	26(92.9%)	86.7%	23(76.7%)	1.3	31.3 (0.2,186.8)	35.1%
7	27(90.0%)	22(81.5%)	73.3%	18(60.0%)	0.8	43.6 (0.3,168.7)	36.4%
8	26(86.7%)	13(50.0%)	43.3%	13(43.3%)	2.0	30.2 (0.2,178.7)	41.5%
9	28(93.3%)	16(57.1%)	53.3%	4(13.3%)	1.4	109.5 (0.2,429.5)	13.2%
10	30(100.0%)	23(76.7%)	76.7%	1(3.3%)	1.8	29.1 (0.8,168.4)	42.6%
11	15(50.0%)	6(40.0%)	20.0%	7(23.3%)	0.9	85.4 (4.5,245.5)	15.4%
12	26(86.7%)	21(80.8%)	70.0%	16(53.3%)	4.2	31.3 (0.4,256.5)	54.1%
13	22(73.3%)	11(50.0%)	36.7%	10(33.3%)	1.1	46.3 (1.0,190.8)	28.0%
14	24(80.0%)	20(83.3%)	66.7%	18(60.0%)	1.1	32.1 (2.6,254.5)	40.7%
15	25(83.3%)	16(64.0%)	53.3%	12(40.0%)	1.8	34.0 (0.1,233.9)	39.1%

Green indicates: above medium
U_T: usage of tracking (adherence)
Q_T: quality of tracking
D_VU: density of valid use
U_CUP: usage of cup device
D_P: dosage of prompts received per day

R_L: response latency, the time elapsed between the triggering of the prompts and the onset of the next break (although user could have taken the break without an intention to respond to that prompt)
C: compliance, the percentage of prompts responded to with a latency of 15 minutes or less
Green: above 50%
*A day was considered a use day of the cup device if accelerometer readings recorded by the cup device exceeded a certain threshold to be considered a drink-like events, regardless of validity of wear device tracking
Recorded cup use positively correlated with quality of tracking for wrist device
Below-medium cup use: P2, P5, P9, P10, P11, P13, P15
decrease in 8 participants (P5, P6, P7, P9, P10, P11, P12, P13)
increase in 5 participants (P2, P3, P4, P14, P15).
Statistically Significant

Participant 1

Basic information: female, admin, 40-49 years old, used her own phone for the study, supportive to digital innovations

Study period: Oct. 2017 - Dec. 2017

Work environment: used a sit-stand desk in office. Sharing office with P2. Described her work as 'autonomous', involving a mixture of independent desk-based work and meetings/out-of-office work.

Motivation: explore behavioural insights and health outcomes.

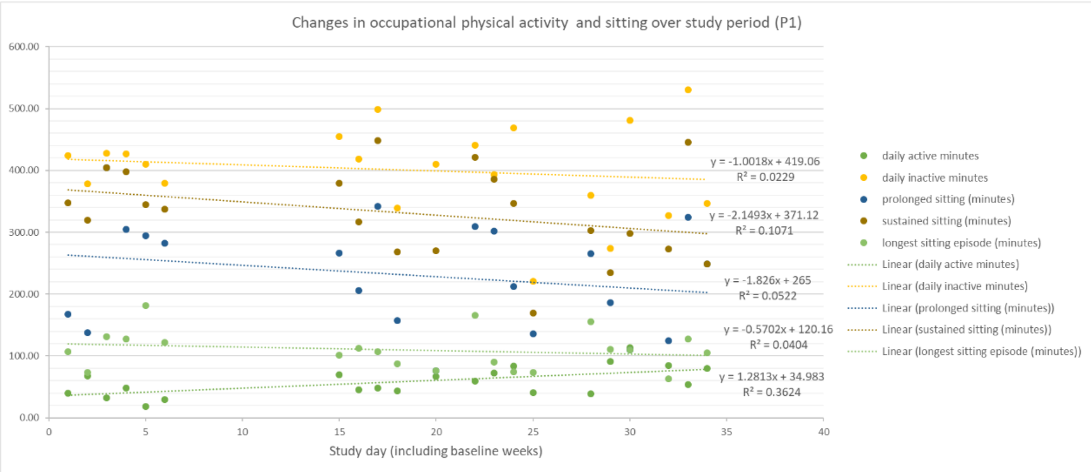
Experience: trusted the system overall speaking, despite frequent connectivity problems at the beginning. Received timely and frequent troubleshooting support from the researcher because the offices were closely located. Reported the tracking as 'accurate most of the time', but with occasional 'false negatives' ('I found sometimes when I went to make a drink, it stayed red'), which were, however, positively perceived because they made her move more and have more drinks. Had not explored the 'history' or 'reward' sections much, but would love to explore them more if she could use the system for longer and the data was okay in the long term; did not update goal or reminder setting. Found the technology easy to be embedded into everyday routine.

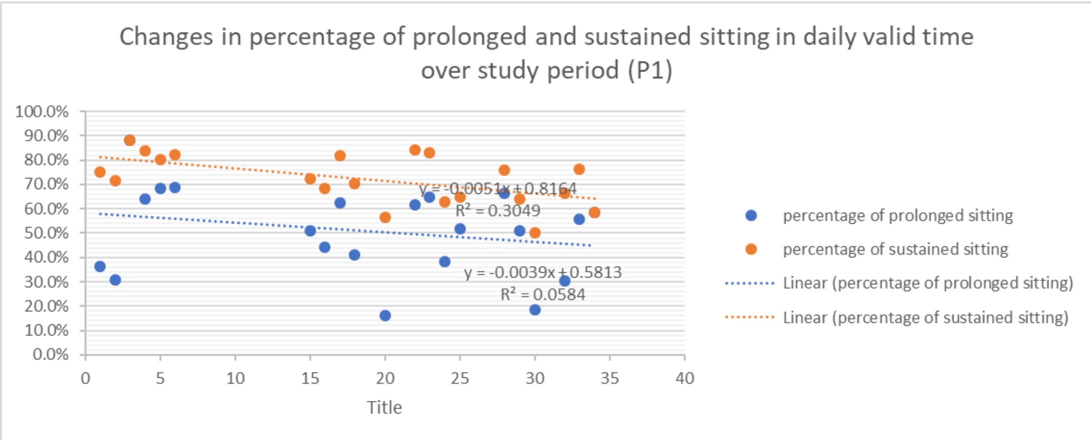
Usage pattern: contributed 21 days of tracking and 15 days of valid tracking days' worth of data; did not take the LED reminder to meetings or on out-of-office workdays. Opted in to continued use post-study, used it irregularly and stopped about 11 weeks later.

Perceived change and reasons for change both behavioural and cognitive change. became more active; the LED reminders reminded her of time and the need for breaks; the visual feedback (colour-coded timeline) made her consciously think about her days and breaks, an effect that would carry on even after the study.

Observed change: increase in daily ambulatory time based on tracking data ($p=.004$); decrease in self-reported SB.

Other things to note: used her own Android phone for the study. More used to a smart wristband (e.g. FitBit) than a smart cup; organisational culture was encouraging but it was more down to the individual.





Participant 2

Basic information: female, admin, 40-49 years old. supportive to students' research work on digital innovations.

Study period: Oct. 2017 - Dec. 2017

Work environment: Used a sit-stand desk in office. Sharing office with P1. Mostly desk-based work.

Motivation: improve health, wellbeing, alertness and productivity

Experience: highly motivated at the beginning, set herself a challenge to take a micro-break to beat the 'red', but later put off by the tech problems. unmotivated to take breaks even when prompted, partly because of work, partly because of 'loss of trust' in the technology. The tracking was often inaccurate (false negative). Liked the visual feedback, thought it was a clear representation of activity. Had not explored the 'history' for day-to-day comparison. Constantly checking the screen throughout the day to see if it was connected rather than for behavioural insights Found the technology easy to be embedded into everyday routine, but troubleshooting caused interruptions to work; thought there was something really good about it, but the tech needed development.

Usage pattern: contributed 20 days of tracking and 14 days of valid tracking days' worth of data; did not continue using the tech after the study, because of job change.

Perceived change and reasons for change: found herself more sedentary toward the end of the study; reported increasing workload, but not the technology, as the main reason for the change in behaviour; chose to ignore reminders as wasn't sure if it was working properly.

Observed change: sig. increase in prolonged SB based on tracking; increase in self-reported SB.

Other things to note: suggested incorporating hydration feedback, because it's important to stay hydrated throughout the day; organisational culture would strongly encourage implementation of *WorkMyWay*; exceptional case where leaving the university and increased workload should be the main reason for increased sitting.

Participant 3

Basic information: female, admin, 30-39 years old

Study period: Oct. 2017 - Jan 2018 (paused during Christmas break)

Work environment: open plan office. Mostly desk-based work

Motivation: concerned about the amount of sitting at work, want to improve health

Experience: the tracking was sometimes inaccurate (false negative), because of Bluetooth connectivity issues, but she could relate to some of the data for self-reflection. liked receiving badges and viewing the numerical summary, but did not use it to guide action. Totally forgot about the goal setting function. Recalled receiving many (7 to 8) prompts per day

Adherence, efficiency and overall acceptance: contributed 28 days of tracking and 20 days of valid tracking days' worth of data; expressed the wish to keep using it even before the researcher asked, because she 'got really used to it' and 'would like to continue having the light reminding her to get up and walk'. carried on using it quite regularly for another 8 weeks, although the quality of post-study tracking was low (i.e. mostly invalid days).

Perceived change and reasons for change: both behavioural and cognitive change. Recalled receiving quite a lot of prompts each day, and would normally take a quick break in response. Also filled up the water bottle more regularly and drank more, which in turn increased frequency of toilet breaks. More conscious of having lunch at desk and sitting in general. Was not so susceptible to retrospective feedback.

Observed change: n.s. increase in prolonged SB based on wearable data; reduced sitting, increased PA based on questionnaire data.

Other things to note: thought it made sense and worked for her to have a break reminder attached to the water bottle, and would love to see hydration data integrated. But she would not take the water bottle to meetings, in which case it would be disruptive to work and be perceived negatively. Heavier workload, colder weather and changes in family life toward the end of the study could have accounted for the increased sitting.

Participant 4

Basic information: male, 30-39 years old, HCI researcher, very high technology literacy

Study period: Oct. 2017 - Dec. 2017

Work environment: private office. Used a standing desk in office. Sitting down for occasional meetings.

Motivation: 60% for personal health, 40% to learn about the activity tracking technology

Experience: found the technology working well for the first 3 weeks but had some data problems in the second half of the study; thought it would have been nice to have it work well for a whole 6 weeks. Found it easy to incorporate it into everyday routine, except for having to fix Bluetooth connections. Quickly reviewed 'history' at the end of each day, found it mostly accurate but with false positives (e.g. meeting talking classified as active); also used the 'history' view to show others what the study was about. Engaged with the visual feedback most mainly to see proportions of different colour sections. Unmotivated by the badges, which were rewarded almost every day. Thought the reward rules or some of the numerical summaries did not make much sense. Updated the goal only once and then did not used the tab afterwards, considered the warning setting more as a 'goal'.

Design insights: Liked feedback in the form of 'x breaks on time' and 'x number of times one sat for too long'. Raised a question on whether the feedback 'x breaks on time' implies 'do not take too many breaks, just take it right on time'. Thought the KPI was unfair as he was only 'naughty' for 6 minutes (sat for 69 min) and it made 30% of the pie chart red. A buzz on the phone might me more noticeable but the colour on mug was good to indicate different stages. Very positive about the future of healthy mugs.

Adherence, efficiency and overall acceptance: contributed 28 days of tracking and 23 days of valid tracking days' worth of data; when the study ended, opted in and carried on using it quite regularly for another about 10 weeks, paused for 4 weeks, and then used it irregularly for another 6 weeks, which set the record for longest post-study use in the sample. Would recommend the technology to students both for health and productivity.

Perceived change and reasons for change: more breaks, but mainly as a result of being more diligent in taking breaks and actively monitoring himself, rather than relying on prompts. Used the 3 reminders with different LED patterns as cues for different actions (i.e. action planning and implementation intention), but would not describe it as ‘automatic’. usually checked the phone even when the reminder was facing away or not working.

Observed change: n.s. increase based on wearable data; decreased standing (-96 min/day), which was replaced with sitting (+48 min/day) and walking (+48 min/day), based on questionnaire data.

Other things to note: would love the tech to track work and leisure activities out of office (i.e. appreciate the portability); took it to meetings and would find it more acceptable and less embarrassing if the ‘tap to snooze’ function was working; thought it could be used to prompt breaks in meetings, since the organisational culture encouraged breaks.

Participant 5

Basic information: female, admin, 60-69 years old, lacked competence and confidence in using technology, but supportive to research

Study period: Oct. 2017 - Dec. 2017

Work environment: private office, close to P7 and P9. Mostly desk-based work

Motivation: motivated by the fact that colleagues were also participating, the desire to help CS students with and the bonus of an Amazon voucher

Experience: encountered tech problems almost every day and found them at times annoying and disrupting work. The researcher ended up coming to help with setup every morning. P5 felt embarrassed for not doing it right and worrying it might not be helpful for research. Would always comply with the suggestion to take breaks, but the light did no flash at her often because she usually took a break before 45 min. Regularly checked the study App throughout the day mainly to see if the tracking was working, but not for feedback on sitting, though it was nice to know she was not sat down for too long. Did not explore ‘history’, ‘reward’ or ‘goal setting’ functions. Did not like the physicality of the wrist or cup devices: attached the LED reminder to one cup but used a different cup for drink, because the LED was in the way of drinking; the band was too tight on her wrist.

Adherence, efficiency and adoption: contributed 26 days of tracking, but only 16 days were valid. Liked the idea of encouraging regular breaks but disliked managing multiple devices. Said although the tech use was easy to be embedded into everyday routine, it was not so useful for her, as she turned out to be quite active already. Did not opt in to post-study.

Perceived change and reasons for change: mainly cognitive, realised she took more breaks than she had thought before.

Observed change: n.s. decrease in SB based on wearable data; increased standing and decreased sitting based on questionnaire data.

Other things to note: thought it was better to combine the devices into one. Co-workers helped each other with troubleshooting. Thought the workplace culture would encourage implementation of the intervention but it should be everybody's own responsibility to take enough breaks. .e.g. 'I wouldn't take on responsibility of anyone else's device flashing (in a meeting) and say ought to move'.

Participant 6

Basic information: male, admin, 30-39 years old

Work environment: open plan office, mostly desk-based work

Study period: Oct. 2017 - Dec. 2017

Motivation: concerned about being sedentary at work and interested to collect some data about his physical activity at work

Experience: found the study experience really positive and the tech predictable, and working relatively well ('I Knew what to expect to output from the cup device to me'). Sometimes it took efforts and time (20 seconds ~ 15 min) to set the connection up in the morning, which was identified as the main barrier to using it. But then got really used to it. Found the App easy to navigate. Usually explored the visual feedback at the end of each day to reflect on the day, did not pay much attention to the badges or numerical summary. Changed reminder setting (referred to it as 'changing the goal'). Occasionally the cup device was facing away but placed next to the monitor and still accessible to the periphery of attention. Would usually follow the prompt and took a break.

Adherence, efficiency and overall acceptance: 28 tracking days and 26 valid tracking days. said it had become part of the everyday routine, opted in to post-study use, but did not have the chance because of Christmas and shortage of study devices for phase II participants after Christmas. Understood the process researchers need to go through to make outcomes worthwhile and useful. Thought *WorkMyWay* was pretty light-touch and easy to adopt.

Perceived change and reasons for change: more walking, which could be a result of using *WorkMyWay* or just changes at work; but the prompts made him more aware of sitting time while working; he also effortfully tried to follow what the tech told him to do.

Observed change: sig. decrease in prolonged SB based on wearable data; increased PA based on questionnaire data.

Other things to note: attaching the reminder to a water bottle made sense and worked for him, as he took the water bottle everywhere on workdays. took it to meetings and would find it more acceptable if the 'tap to snooze' function was working. Thought the organisational culture encouraged breaks. But for it to work in meetings and changed the culture, everyone needed to buy into it and then someone got to take the lead to initiate a break. Sometimes in the mindset of 'I could get away with that because I've done active stuff for the day.'

Participant 7

Basic information: female, admin, 50 - 59 years old, used her own phone for the study, limited technology literacy

Study period: Oct. 2017 - Dec. 2017

Work environment: private office, close to P5 and P9. Work was mostly desk-based, independent and not particularly supervised**.** Not tech savvy.

Motivation: get insights into her own sitting behaviour

Experience: the technology was oversensitive in picking up within-office movements (e.g. put something into the bin, open the blind, even typing) as breaks, which she would consider as activity but not 'breaks' (false positives). When taking her phone out of range of the cup device, the App kept notifying her of 'data problem', which was annoying. Encountered Bluetooth connectivity problems throughout, and tried killing the App multiple times but in vain. Handy to have the researcher in the building ready to help. Written instructions are not as helpful as someone showing her the steps. Can see tech was improved and became accurate ('It feels actually as if it's got better as it's gone along'). Changed the reminder interval from 45 min to 60 min. Hooked the LED reminder to a fan on the desk and would put it into pocket while taking a break; but did not recall seeing many lights. Often had a quick look at the feedback during the day when doing something else on her phone, mostly to check if it was connected; did explore day summaries forward and backward. Did not explore reward or goal setting function.

Adherence, efficiency and overall acceptance: contributed 27 tracking days and 22 valid tracking days. Using the tech took up some time at work. Sometimes forgot to take it off before leaving. Did not opt in to post-study use because she learnt from the study that she was quite good with break routines anyway.

Perceived change and reasons for change: only cognitive, realised she moved more than she had thought before, which was encouraging; did not change her routine ('I'm in a routine of getting up and going for a drink mid-morning and mid-afternoon any way. That's what I do. I think if it's flashing around that time, I took notice of it. But if not, then it wasn't really relevant').

Observed change: sig. decrease in prolonged SB based on wearable data; increased PA based on questionnaire data.

Other things to note: suggested combining the devices into one. the data would be more informative if the detection was less sensitive. Describe herself as reasonably conscious of occupational sitting problems: try to take a 5-min tea break mid-morning, mid-afternoon and going for a walk after lunch.

Participant 8

Basic information: female, academic, 30 – 39 years old

Study period: Nov. 2017 - Jan. 2018 (paused during Christmas breaks)

Work environment: private office, Mostly desk-based work plus some teaching time

Motivation: noticed that she did not take enough breaks while working alone and if under stress. Would like to get 'hard data' about her work break pattern (primary goal) and hopefully change break behaviour in stressful situations (in the future). Took the devices off in meetings.

Experience: encountered data problems and fount it frustrating and confusing, because it seemed to be 'random' and she didn't know what she should do differently to fix it. Annoyed by the error notification that repeats itself throughout the day even though the data has been received by the App and visualised on screen (note: possibly the notification was about cup disconnection or logic error in dismissing notification). Sitting while talking was classified as active (false positive) at the beginning of the study, not an issue after having the researcher adjust the thresholds. Really liked the colour-coded feedback, explored the visual and numerical feedback mostly at the end of each day while actively reflecting on the day. But did not use the feedback to guide behaviour for the following day. On stressful days, also looked at the App for real-time feedback on sitting to persuade herself to take a break in the moments of working. Would prefer having the reminder stuck on the monitor to better catch her attention. Only updated goals once. Received badges even for bad days.

Adherence, efficiency and overall acceptance: contributed 26 days of tracking, but only 13 days were valid. Found it easy to embed the tech use into everyday routine, but often forgot to stop tracking at the end of each day. opted in to post-study use, carried on intermittently for 5 weeks with low data quality and paused for 7 weeks due to connectivity problems; after having researcher fix the connection, she resumed use for another 2 weeks and then stopped, likely due to connectivity problems again.

Perceived change and reasons for change: she did not have the intention to change behaviour over the study period and the study did not strengthen her intention to take breaks, because the feedback was descriptive rather than instructive or persuasive. But during the time of the breaks that she would normally take, she might have walked around for longer with the intention to check if the tracking function was working. Although the LED flashes were not invasive enough to catch her attention or stop her from working, she might have taken more breaks as a result of noticing some of the prompts. When presented with the data showing increase in prolonged sitting, explained it was because the baseline was during a quieter period of the year whereas the last few weeks in the study was really stressful.

Observed change: flat trend based on wearable data; decreased sitting and movement-based PA (walking and heavy labour) based on questionnaire data.

Other things to note: would love it to start and stop tracking workday automatically. The App should support behaviour change by providing advice more actively, such as suggesting practices for sitting reduction, in which case she maybe would follow it.

Participant 9

Basic information: female, senior admin, 50-59 years old, staff wellbeing board member

Work environment: private office, close to P5 and P7. A mixture of desk-based work and meetings, very often out of office.

Study period: Nov. 2017 - Jan. 2018 (paused during Christmas breaks)

Motivation: as the staff wellbeing lead, keen on understanding anything that could potentially be used to promote work health and wellbeing. Also to get insights into her own behaviour and opportunities for improvement.

Experience: found it interesting to see activities being tracked and visualised in real time, the LED prompt was useful to notify her of sitting. Tech problems were frustrating. Used the 'Track' and 'History' functions the most, liked the glanceable design of the cup LED reminder, was initially dependent on it for break signals. But then found it unreliable and less portable than the smartphone, so switched to look up on the App in the later part of the study. Tried to take the cup device to meetings but left in the bag most of the time. Would have used the LED reminder on cup more often if her work was not so mobile (ie. main barrier to use the cup device was the mobility of her work). When receiving reminders, would try to get up in the next 5 minutes or draw a meeting to a close if it was naturally approaching that point. The numerical summary was used to see at the end of the day but she tended to engage with the real-time visual feedback during the day to guide break decisions. did not use 'Reward' or 'Goal Setting'.

Adherence, efficiency and overall acceptance: 28 tracking days but only 16 valid tracking days. opted in to post-study use but had to return the devices earlier because participants in Phase II needed them.

Perceived change and reasons for change: the tracking and prompting made her much more aware of long periods of sitting in the situations; also helped recognise the natural breaks she took by moving between meetings, which she had not thought as breaks before. Despite tech problems, she had learnt to take breaks anyway. Attributed the observed increase in prolonged sitting to the 2 highly sedentary training days in week 8.

Observed change: n.s. decrease in prolonged SB (but decrease in sustained SB) based on wearable data; decreased sitting (-45.3 min/day), increased PA and decreased sitting based on questionnaire data.

Other things to note: The technology triggered conversations among colleagues and family members (eg. her daughter) about health and generated interest. The workplace is encouraging of regular breaks but some roles required breaks to be more controlled (eg. student facing roles). Suggested designers and implementers of the intervention considering how it would fit in with different job roles and the cost for the department to roll out the intervention. Very keen on promoting *WorkMyWay* to the university if the study concluded that some people actually found it useful.

Participant 10

Basic information: female, admin, 30-39 years old

Work environment: open plan office, mostly desk-based work

Study period: Feb. 2018 - Apr. 2018

Motivation: concerned about her sedentariness at this new job, would like to monitor her activity at work and to reassure herself that she actually took regular breaks by engaging with the data

Experience: despite tech issues, she got really into the App and engaged with the data. Thought the tracking was 90% accurate. Usually explored history at the beginning of the day, liked the visual and textual feedback ('congratulations, better than yesterday'), but did not pay attention to numerical summaries; the badges in the history was her favourite feature, but did not really explore 'reward' section separately; also found the numerical feedback useful when directed attention to it in the interview. The LED reminder was placed on the bottle in front of her near the screen, but she did not take the bottle for a walk because she normally had hot drinks with a cup instead. For the modalities of reminder. a beep or vibration might be a better modality for her, as she was often too focused on work to notice the LED. With that said, colleagues past her often noticed the LED and reminded her to take breaks.

Adherence, efficiency and overall acceptance: 30 tracking days and 23 valid tracking days. Expressed a strong interest to continue to use the technology; she carried on for 3 weeks post-study, with low data quality for the last 2 weeks, and stopped use afterwards.

Perceived change and reasons for change: more breaks and particularly lunch walking breaks, mainly as a result of knowing herself was being tracked by the technology and given feedback on behaviours, along with the existing awareness of health benefits.

Observed change: n.s. decrease in prolonged SB based on wearable data; increase in standing and decrease in ambulatory time based on questionnaire data.

Other things to note: suggested improvement – pointing out the swipe-navigation of the summary tabs at the bottom would be useful; prefer vibratory to visual modality;

Participant 11

Basic information: female, academic, 20-29 years old, P15 in Behavioural Diagnosis Study

Study period: Feb. 2018 - Apr. 2018

Work environment: sharing office with 3 colleagues. A mixture of desk-based work, training and fieldwork, very often out of office

Motivation: to improve health and wellbeing

Experience: leaving the room in a rush without taking the phone caused many gaps in the data; encountering connectivity issues, which could usually be resolved by performing the 'kill app - reset connection' procedures; but even when devices were well connected, some mini-breaks (1 or 2 minutes) were not detected or registered (false negatives), which was frustrating. The LED reminder was her favourite function; she also preferred light to buzzes as the modality of communication, because light was subtler, less disturbing to surroundings and made her physically look away from what she was doing. Though found it hard to take breaks immediately following the prompts; often had to ignore them or postpone the breaks for a few minutes because of meetings/phone calls. the reminder was fixed to her water bottle and very visible at eye level, there was never a time where it went off and she didn't see it. As she usually took a break before the light went off, so she didn't always discover the problem immediately after it occurred. The colour-coded feedback really motivated her to get better in taking breaks and avoid the 'red', also liked numerical summaries and the icons. The feedback usually confirmed her own experience of the day and led to the awareness that she was much more productive when she have had a mini break. Did not pay attention to 'rewards' or badges.

Adherence, efficiency and overall acceptance: 15 tracking days and 6 valid tracking days. Opted in to post-study use but stopped in less than 2 weeks. Usage was very intermittent and quality of tracking low both during and after the study.

Perceived change and reasons for change: took more breaks because of receiving the LED reminders and a sense of guilt induced by the historical feedback; the reminder also helped her get into the routine of looking up every hour and noticing the need for breaks; if she carried on for months, there was the potential for behaviour change to be sustained even after removal of LED reminder.

Observed change: n.s. decrease in prolonged SB based on wearable data; increased sitting and standing, and decreased movement-based PA based on questionnaire data.

Other things to note: the wristband triggered conversations among colleagues about the study and work health; when someone was over at P11's desk asking questions, the LED cup device prompted them to take a break together. In a department full of occupational therapists and physiotherapists, where the culture would encourage the scaling up of the technology.

Participant 12

Basic information: female, admin, 51-59 years old, P7 in Behavioural Diagnosis Study

Study period: Feb. 2018 - Apr. 2018

Work environment: sharing office with 3 colleagues, including P13 and P14. A mixture of desk-based work, training and meetings.

Motivation: aware of the need to take regular breaks for health, need prompts to interrupt her and some feedback to check how long her sitting was

Experience: overall positive experience, despite tech problems. Disliked the fact that the App did not notify her of error unless she checked the phone. Liked the tracking and real-time visualisation; did not use the history at the beginning as there wasn't much history for day-to-day comparison; but later figured out the pie chart and found it a very nice representation of the amount of sitting on each day. Did not understand the rewards. Got prompts/cues for breaks from both the cup and the App as she regularly checked the phone to see if it was working. Would usually follow the prompts and took a break unless in meetings. Strongly motivated to utilise the technological cue and change behaviour. Initially thought the glass was the best medium for reminding her, but then found it usually out of her field of vision while she was typing. Thought the micro-break recognised as 'active' by the App and reset the clock was not sufficient for her. Hence, in post-study use, she attached the reminder to her keyboard and asked the researcher to enhance the break detection threshold.

Adherence, efficiency and overall acceptance: 26 tracking days and 21 valid tracking days. Opted in to post-study use, carried on using it regularly for 6 weeks; reduced usage from week 7 and stopped in week 10 after the study because of connectivity issues.

Perceived change and reasons for change: cognitive - realised she got more breaks than she had thought before, and behavioural – took more breaks. Main enablers: the real-time on-screen visualisation and all 3 officemates participating and prompting each other. Negative influences: at the beginning, the absence of LED flashes because of data problems might have misled her to sit for longer; toward the end of the study, she might have sat for longer in order to fix the connection.

Observed change: n.s. decrease in prolonged SB based on wearable data; more active based on questionnaire data.

Other things to note: reported the wristband was unpliant to wear in hot weather. Can't touch type (look up while typing), and hence missed some reminders. The fact that co-workers in the same office were in the study together really facilitated technology use (e.g. helping each other troubleshoot) and behaviour change (e.g. reminding each other of the flashes).

Participant 13

Basic information: female, admin, 51-59 years old,

Study period: Feb. 2018 - Apr. 2018

Work environment: sharing office with 3 colleagues, including P12 and P14, A mixture of desk-based work, training and meetings

Motivation: To improve wellbeing, reduce fatigue; need prompts to get up regularly.

Experience: positive experience, despite tech problems. It was ease to integrate tech use into everyday life. But by the time she saw the light she had already got up; easy to miss reminder if concentrating on work. Liked the colour-coded timeline in real time as well as in history and rewards. Compared data between days only occasionally, because she wasn't certain about the accuracy of all data. Considered it a reward to see a lot of 'green' and show that to colleagues. Discussed each other's visualisation during workdays both for troubleshooting and reflection on behaviour. Used the diary entry quite often to report breaks unrecorded during disconnection. Would love more transparent information about the system status (whether it was recording all the data) .

Adherence, efficiency and overall acceptance: 22 tracking days, out of which only 11 were valid tracking days. Opted in to post-study use, carried on using it quite regularly for another 5 weeks or so, but most days were invalid.

Perceived change and reasons for change: both cognitive and behavioural. Became more aware and conscious of her sit-break pattern, and started keeping track of sitting time using the clock on the phone and computer when *WorkMyWay* was not working.

Observed change: n.s. decrease in prolonged SB, although there was insufficient wearable data; increased SB based on questionnaire data.

Other things to note: reported the wristband was unpliant to wear in hot weather. Felt it was absolutely fine to incorporate social functions into the system and share data with colleagues/managers. Co-workers helped each other troubleshooting, discussed each other's graph and reflected on behaviours.

Participant 14

Basic information: female, admin, 30-39 years old

Study period: Feb. 2018 - Apr. 2018

Work environment: sharing office with 3 colleagues, including P12 and P13

Motivation: disliked sitting at desk all day at work, need prompts to get up more regularly, A mixture of desk-based work, training and meetings, occasionally out of office

Experience: mostly positive, despite occasional connection problems. Liked the tracking and real-time feedback most, as it got them out of the office regularly. Though the office had occasionally missed the reminder if the LED on the bottle was facing away or they were engrossed in work, they would always remind each other to get up if one of them noticed a reminder. Not recalled receiving many prompts, because they always checked the phone before 45 min of sitting and took a break to avoid the flashes. Liked receiving "rewards", but gave up towards the end of the study because no more badges were awarded. Felt the reward reflected her own evaluation of the day. Did not explore history or compare different days, as she thought it depended on how busy she was rather than how much she paid attention to taking breaks. Experienced false negatives. Would like to be notified of errors.

Adherence, efficiency and overall acceptance: 24 tracking days, of which 20 were valid. Opted in to post-study use, used it intermittently for 4 weeks, with only 1 valid tracking day.

Perceived change and reasons for change: took more regular breaks, because (1) participation in the study raised awareness of the issue; (2) they used the real-time feedback on inactive time to guide action before the light went off; (3) participating officemates regularly prompted each other to get out of the office for breaks together. Drank more water because the reminder was fixed to her water bottle.

Observed change: n.s. increase in prolonged SB based on wearable data (although the participant disagree); no change based on questionnaire data.

Other things to note: participation as an office was fun; disliked wearing the band.

Participant 15

Basic information: male, academic, 20-29 years old, P10 in Behavioural Diagnosis Study

Study period: Feb. 2018 - Apr. 2018

Work environment: sharing office with 3 colleagues. A mixture of desk-based work, training, occasionally out of office.

Motivation: aware of long sitting (3-4 hours) especially when he was programming; wanted to be prompted and even enforced to take regular breaks to improve productivity.

Experience: liked the concept and design. occasionally did not notice the reminder until 30 minutes after it was triggered because the LED was facing away; would always notice the LED if it was facing him. But was in two minds regarding whether an audible reminder would be better. Explore the history at the end of each day and compared between days. Could relate to the feedback – days with regular 'greens' felt much more productive than days with red blocks. Tried to avoid reds. Liked visual feedback the best. Did not pay much attention to pie charts, numerical summaries, or badges.

Adherence, efficiency and overall acceptance: Used it on most days of the week throughout the study. 25 tracking days, of which 16 were valid. Did not opt in to post-study use because the wristband was unpliant to wear in hot weather.

Perceived change and reasons for change: took more breaks as a result of being reminded by the presence of the wrist and cup devices, and even more when it flashed, which he associated with taking breaks; the LED flashes worked as a reminder to wrap up work to take a break soon. Bur there was potential for developing automatic responses. When the connection was broken, he reverted to the previous pattern, rather than sat for longer.

Observed change: increase in prolonged sitting based on wearable data; more active based on questionnaire data.

Other things to note: reported the wristband was unpliant to wear in hot weather. if the whole office is using the tech, they are better all synchronised to avoid distractions.