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

Abstract

Background: There is a clear public health need to reduce office workers’ sedentary behaviours (SB), especially in the workplace. Digital technologies are increasingly being deployed in the workplace to measure and modify office workers’ SB. However, knowledge of the range and nature of research on this topic is limited; it also remains unclear to what extent digital interventions have exploited the technological possibilities.

Objective: To investigate the technological landscape of digital interventions for SB reduction in office workers and to map the research activity in this field.

Methods: Terms relating to SB, office worker, and digital technology were applied in various combinations to search Cochrane Library, JBI Database of Systematic Reviews, MEDLINE, PsycArticles, PsycInfo, Scopus, ACM Digital Library, Ei Compendex, and Google Scholar for the years 2000 to 2017. Data regarding the study and intervention details were extracted. Interventions and studies were categorised into development, feasibility/piloting, evaluation or implementation phase, based on the UK Medical Research Council (MRC) framework for developing and evaluating complex interventions. A novel framework was developed to classify technological features and annotate technological configurations. A mix of quantitative and qualitative approaches were used to summarise data.

Results: We identified 68 articles describing 45 digital interventions designed to intervene with office workers’ SB. Less than half of them were theory-informed, and even fewer were developed following a systematic methodological framework. Six common technological features had been applied to interventions with various combinations. Configurations like ID & MOSSI (Information delivery & mediated organisational and social support), and DL & ATF (digital log & automated tailored feedback) were well-established in evaluation and implementation studies; in contrast, the integration of passive data collection (PDC), connected devices (CD) and automated tailored feedback (ATF) or scheduled prompts (SP) were mostly present in development and piloting research.

Conclusions: This review is the first to map and describe the use of digital technologies in research on SB reduction in office workers. Interdisciplinary collaborations can help to maximize the potential of technologies. As novel modes of delivery that capitalised on embedded computing and electronics, and wireless technologies have been developed and piloted in engineering, computing and design fields, efforts can be directed to moving them to the next phase of evaluation with a more rigorous study design. Quality of research may be improved by following a systematic intervention framework and adopting a phased approach to conducting and reporting studies. This
review will be particularly informative to those deciding on areas where further research or development is needed.

Keywords: sedentary behaviours; office workers; technology; applications

Introduction

Background
Sedentary behaviours (SB) are activities that require very low energy expenditure of < 1.5 metabolic equivalents (METs) and typically involve lying down and sitting [1]. SB is found to be associated with increased risks for metabolic dysfunction, musculoskeletal disorders, some cancers, premature mortality, and various other health conditions, irrespective of the amount of moderate to vigorous physical activities [2–5]. Sedentary time can accumulate in different contexts such as during leisure time, transportation and in the workplace. A number of studies [6–8] have found office workers’ within-work time is characterised by more prolonged SB with fewer breaks than non-work time; sedentary work contributes significantly to overall sedentary exposure of office workers and thus the health risks. Therefore, there is a clear public health need for interventions that target the reduction of SB in this setting and population. In this paper, we focus on a potential solution: SB interventions delivered with digital technologies.

According to Oxford Dictionary, digital technologies refer to technologies involving or relating to the use of computer technology, which include tools, systems, devices and resources that generate, store or process data in the form of digital signals. The past decades have seen an exponential growth of computing power at affordable prices. This has resulted in an increasing variety of digital gadgets (e.g. PC, tablets, smartphones, wearables, Internet of Things) that a person is exposed to and interacts with on a day-to-day basis. This presents health intervention designers and researchers with a wider range of device choices that offer different form factors and features. Indeed, digital health has demonstrated great promise in a range of clinical settings and populations in terms of behavioural measurement and intervention delivery (e.g. paediatric care - [9]; mental health - [10]).

However, when it comes to digital SB interventions, the behavioural target of ‘being less sedentary’ and the use of digital media seem to present us with a paradox here. First, the increase in sedentary occupations and sedentariness at work in itself is closely related to the evolution of digital technology, which enables more work to be completed at desks without manual labours or even light physical activity. Second, a recent study [11] has found that information and communication technologies (ICTs) have supported new break activities in the office (e.g. checking social media during mini-breaks or watching videos over lunch breaks) while evoking negative feelings at the same time. The researchers used the term ‘screen guilt’ to describe office workers’ need to disconnect from screen-based ICTs during breaks for both physical and psychological wellbeing.
This has led us to rethink what (or even whether) digital features should be incorporated when designing SB interventions. The intersection of digital health and SB has attracted a lot of research interest and accumulated a large body of empirical evidence in recent years. As a first step in our own research on exploiting novel digital technologies for the delivery of workplace SB interventions, we wanted to review the literature in a systematic manner, to have a better understanding of the technological landscape, and to determine gaps in terms of utilising technologies for SB research.

**Previous Reviews**

To date, six systematic reviews on SB interventions have been published [12–18]. This section overviews which aspects of the topic have been addressed in those reviews and what are still lacking.

Freak-Poli and colleagues’ review [12] was focused on one particular type of digital interventions, namely pedometer-based interventions for increasing PA and reducing SB in the workplace. Restricted to randomised controlled trials (RCTs), the review included only four studies and suggested there was insufficient evidence to determine the behavioural or health outcomes of workplace pedometer-based interventions. The other three reviews [13,16,17] were inclusive of all SB reduction interventions regardless of the presence of digital elements. Chau and colleagues [13] reviewed studies published up to April 2009 and identified only six eligible workplace studies that included sitting as an outcome measure. Only two types of digital media were covered (emails [19–21]) and pedometer [19]). Measurement of SB was self-report in all six 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 [13], a more recent review [16] by Shrestha and colleagues identified 20 eligible 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 three studies [22–24]). Second, it compared the effect of different contents in e-newsletters on sitting reduction, based on one study [25]. The findings from both analyses were non-significant or inconclusive given the low quality of evidence. The most recent review by Chu and colleagues [15] included 26 studies published up to December 2015 and classified them based on intervention strategies into three 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 [15], Gardener et al.’s review [17] 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 [26] and behaviour change
techniques (BCTs) [27]. They found that education, persuasion, environmental
reconstructing and training were the most promising intervention functions and that
self-monitoring, problem solving, changing the social or physical environment were
particularly promising BCTs for reducing SB. Martin and colleagues’ review [18] 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.

While shedding light on intervention strategies and components effective for reducing
workplace SB, those reviews fell short in two 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 [28]. 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 the next generation of digital interventions in due course. An
exploratory search of the computer science literature has found an abundance of user-
centred design research [29] on technologies targeting SB reduction. Those studies
have gathered valuable data about design-related outcomes (tech feasibility, usability,
acceptability) at an early stage of intervention development, which would both inform
the improvement of technology design and indicate the potential user uptake, attitude
and adherence to different intervention technologies should the interventions be
moved to later stages of development and evaluation. As yet, awareness of the size and
location of this body of evidence is lacking.

The Current Review
In summary, while previous reviews have touched on the technological design in 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. How have digital technologies been used in interventions to reduce office workers’ SB at work?
2. What research has been done on them and what development phases have they reached?
3. Where does the research gap lie in relation to moving promising technological interventions into the next phase?

In view of the above, we selected the approach of scoping review, which is a particularly useful tool to synthesize findings established with different study designs and to address broader topics than those addressed by systematic reviews (e.g. effectiveness) [30].

The present scoping review will be reported with the following structure. Considering the complexity of this topic, we will first review existing classifications and frameworks proposed from several disciplines to describe digital technologies for behaviour change. Second, we present the search and review method. In the result section, we first provide a quantitative summary of studies and interventions identified in this review. Then we focus specifically on the design and application of digital technologies in these studies. As estimation of effects on behavioural or health outcomes is beyond the scope of this review, we narratively summarize study results particularly relevant to technology designs. Finally, we discuss findings and suggest avenues for future research.

**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 [31,32], behavioural intervention technology (BIT) [33], and mode of delivery (MoD) for behaviour change interventions [34]. Here, we review frameworks that categorise digital health technologies based on physical manifestations and functions (both high-level functional roles and specific system features).

**Based on physical manifestations**
Persuasive technology (PT), or computing system, device or application intentionally designed to change a person’s attitude or behaviour, has been categorised into desktop-based, artefact-based and environment-based systems, based on form factors [35]. Desktop-based systems are those only accessible through traditional personal computers and include web pages and emails designed for desktop viewing and computer software. Artefact-based systems are usually portable, and may include smartphones, wearable devices and physically embodied agents, such as robot toys. Environment-based systems refer to computing systems built into the physical space or fixed to facilities to capture behaviours of users of the space or facility and to deliver point-of-choice persuasions, such as a system built into a public restroom to detect and encourage handwashing-with-soap behaviours of all toilet users [36].

**Based on roles and functions**
The Functional Triad of persuasive technology [32] describes three general roles a computer can play in its interaction with the user; namely a tool that increases user
abilities, a medium that delivers content to creates 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 (PSD) model [31] suggested design principles under the following four 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. keeping track of user’s 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. users discern via the system that are others 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 PSD 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 [34] developed a novel scheme to code modes of delivering Internet-based health behaviour change interventions into three 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 [33], referring to actual technical instantiations in the intervention with which the user interacts with. In addition to those functional components included in Webb’s coding scheme, Mohr and colleagues [33] 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 to derive our own method to analyse and compare the technological aspects of interventions to be reviewed.

**Method**

**Search and selection**

An interdisciplinary literature search was conducted of the following databases:
Synonyms and subject headings relating to the following terms were applied in various combinations: office worker, sedentary behaviour, technology, workplace (See Multimedia Appendix 1 for example search strategy). Reference lists of existing reviews on workplace sitting reduction/activity promotion interventions were hand searched to identify additional eligible studies.

Title, abstracts and full text of retrieved articles were reviewed for eligibility by applying the following criteria: 1) having office workers or working age adults with presumably office-based jobs as participants or potential users; 2) targeting SB during work or had proxy measures of workplace SB (objective and/or self-report daily sitting of participants who were primarily office workers); 3) 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; 4) published in peer-reviewed scientific journals/conference proceedings between 2000 and 2017; and 5) in the English language.

Observational studies without administering or developing any intervention were excluded, though design and development research leading to intervention technology prototypes were included. Studies were also excluded if digital technologies were used for purposes other than intervention delivery, such as using digital pre- and post-study assessments without feeding the data into the intervention content in any way.

**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 in if the study country was not specified), 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 two types of outcomes pertinent to the design and use of technology: design-related outcomes informative for future iterations of intervention, which typically included 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 quality of life.
Based on the UK Medical Research Council (MRC) framework for developing and evaluating complex interventions, we categorised the whole or sections in the articles into respective research phases: development, piloting/feasibility, evaluation, and implementation; we also categorise the intervention based on the phase reported in the latest publication about the intervention (Table 2).

Table 2. Definitions of the development and research phases

<table>
<thead>
<tr>
<th>Phase</th>
<th>Definition and examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development phase</td>
<td>Studies could be one of the following: i. reporting the design and development process of the intervention, following approaches like Intervention Mapping, participatory design and user-centred design; ii. lab studies investigating design-related outcomes (feasibility, usability and user experience) before the intervention has reached a deployable state of development; iii. Short in-the-wild deployment studies evaluating specific intervention components within a functional prototype before investing in further development.</td>
</tr>
<tr>
<td>Piloting/feasibility phase</td>
<td>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.</td>
</tr>
<tr>
<td>Evaluation phase</td>
<td>Studies using larger sample size and more rigorous study designs to assess important user-related outcomes and establish the efficacy of interventions.</td>
</tr>
<tr>
<td>Implementation phase</td>
<td>The intervention has already gone through the evaluation phase, and has been used in practice for some time (e.g. &gt;= 2 years). As many implementation efforts are not reported, it was expected that this phase would have low representation.</td>
</tr>
</tbody>
</table>

We adapted existing classification frameworks to derive our own coding scheme to annotate the technological aspect of each intervention (Table 3). The framework was primarily based on the BIT model [33], 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. organisational and management support is added). 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 joint 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 inherently 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 present.

Table 3. Links between our codes and categories from existing frameworks

<p>| Codes with descriptions | BIT elements [33] | Roles in Functional Triad [37] | MoD for Internet-based interventions [34] |</p>
<table>
<thead>
<tr>
<th>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</th>
<th>Log</th>
<th>N.A. (these are considered BCTs rather than MoD in the conceptual framework)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive data collection (PDC): use wearable, smartphone-based and environment-based objective monitors to obtain time-stamped SB records automatically</td>
<td>Passive data collection</td>
<td></td>
</tr>
<tr>
<td>Connected device (CN): one or more external sensing device is connected either wirelessly or with a cable to a central computing device</td>
<td>N.A.</td>
<td></td>
</tr>
<tr>
<td>Scheduled prompts (SP): break reminders delivered either at fixed intervals or with some schedule adaptive to the real-time user status</td>
<td>Notification push</td>
<td>Automated functions: automated follow-up messages (reminders, tips, newsletters), use of enriched information environment, automated tailored feedback based on individual progress</td>
</tr>
<tr>
<td>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)</td>
<td>Information delivery</td>
<td>Medium/social actor</td>
</tr>
<tr>
<td>Automated tailored feedback (ATF): feedback on individual behaviours and progress, including personalised goal setting and recommendations</td>
<td>Reports, visualisation</td>
<td>Medium/social actor</td>
</tr>
<tr>
<td>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.</td>
<td>Messaging</td>
<td>Communicative functions: access to peer-to-peer support</td>
</tr>
</tbody>
</table>

Data synthesis
Results on publication data, study characteristics and research phases were quantitatively summarised and presented using descriptive statistics. As for results on technology design, because of the heterogeneity of study design and outcomes, a qualitative descriptive approach was used compare and contrast technological features and configurations across studies in relation to the research phase.

Results
A total of 68 articles were included in this review (Figure 1), 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 result presentation is divided in two parts: study characteristics and intervention characteristics.
Figure 1. Search and screening results

Study Characteristics

Publication data
As shown in Figure 2, 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. Sixty four published articles represented research that was conducted in 16 countries, in addition to two articles that reported international studies conducted in 64 countries [38] and three countries (the UK, Australia and Spain) [19] respectively. The most represented countries were Australia (n = 19 articles), the US (n = 17), the Netherlands (n = 8) and the UK (n = 4). Another seven European countries (e.g. Austria, Spain, Portugal, Belgium, Germany, Switzerland, Finland) were represented in a total of 20 articles.
In terms of publication avenues, the included articles were published in 40 different scientific journals and proceedings. The most common journals were BMC Public Health (n = 8 articles), American Journal of Preventive Medicine (n = 5), PloS One (n = 5), International Journal of Behavioural Nutrition and Physical Activity (n = 4) and Journal of Medical Internet Research (n = 4). 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).

**Study type**
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. 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. pre-study and post-study interviews), and n = 18 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 the design process and an evaluation study.

**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 two articles that reported both the development and piloting phase [39,40], each article was assigned one category.
<table>
<thead>
<tr>
<th></th>
<th>Number of articles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development</td>
<td>19</td>
</tr>
<tr>
<td>Piloting/feasibility</td>
<td>34</td>
</tr>
<tr>
<td>Evaluation</td>
<td>10</td>
</tr>
<tr>
<td>Implementation</td>
<td>7</td>
</tr>
</tbody>
</table>

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 via local newspaper, social media and from participant pools and ended up with a mixture of office workers and unemployed participants (e.g. [39] - 13 students and 4 office workers; [41,42] -12 retired/employed and 18 office workers; [43] - 2 graduate students and 2 faculty members).

Sixty-three studies recruited participants regardless of BMI, whereas five studies targeted overweight and obese adults [41,42,44–46]; all studies but one [47] included both female and male participants. Except for one design and development study where sample size was not reported, sample sizes ranged from 1[48] to 91[49] among development studies, 3 [47] to 412[50] among piloting studies, 153[51] to 631[52] among evaluation studies, and 291[53] to 69291[38] among implementation studies.

Intervention Characteristics
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 SB reduction element in the intervention design but reported SB change as secondary behavioural outcome.

Theoretical underpinning
N =19 interventions were underpinned by theories, which included theory of planned behaviour (TPB) (n = 5), theories of habits (n = 5), social cognitive theory (n = 4), social ecological model (n = 4), and the stages of change/transtheoretical model (n = 4 interventions). The development of n = 3 interventions followed frameworks (e.g. Intervention Mapping) that supported theory-based intervention design [49,54,55].

Configuration of technological features
Multimedia Appendix 2 details the technological features and configurations implemented in each intervention, the methods used to study those interventions and study outcomes. 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

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Development</th>
<th>Piloting/feasibility</th>
<th>Evaluation</th>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>45</td>
<td>13</td>
<td>21</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>ID</td>
<td>36</td>
<td>9</td>
<td>17</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>DL</td>
<td>14</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>PDC</td>
<td>39</td>
<td>12</td>
<td>18</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>CD</td>
<td>12</td>
<td>6</td>
<td>5</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>SP</td>
<td>26</td>
<td>11</td>
<td>14</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>ATF</td>
<td>29</td>
<td>9</td>
<td>12</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>MOSSI &amp; ID</td>
<td>12</td>
<td>1</td>
<td>3</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>PDC &amp; ATF</td>
<td>26</td>
<td>9</td>
<td>11</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>PDC &amp; SP (JITAI)</td>
<td>19</td>
<td>13</td>
<td>5</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Using on-board sensors</td>
<td>8</td>
<td>6</td>
<td>2</td>
<td>59%</td>
<td></td>
</tr>
<tr>
<td>Using connected sensing devices (PDC &amp; CD &amp; SP)</td>
<td>11</td>
<td>7</td>
<td>3</td>
<td>9%</td>
<td></td>
</tr>
</tbody>
</table>

ID: information delivery; DL: digital log; MOSSI: mediated organisational support and social influences PDC: passive data collection; CD: connected device; SP: scheduled prompts; JITAI: just-in-time adaptive interventions

**ID & MOSSI - 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 [51,56–58]. 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 [38,52,53,59,60].

Two thirds of the ID & MOSSI interventions had moved beyond development and piloting phases, with six interventions [19,51,52,61–63] having reached the evaluation phase, and two [38,53] 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 [19,51,52,59,62,63], except for [61], which delivered a lifestyle intervention with a small component focused on SB reduction and yielded insignificant 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 [64].

**DL & ATF - 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 [20,65,66] to sophisticated visualisation and simulations tools providing feedback on outcomes of self-report behaviours, such as daily step counts [38,52,59] and physical activities (PA) [67,68].

Although only eight interventions were identified in this category, half of them [20,52,59,66] had reached the evaluation phase and one [38] the implementation phase. All report SB reduction in the intervention group over time though only [52,59] 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 [66] 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 [20], 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 might be the provision of pedometers in [66] that made a difference.

Despite a lack of hard evidence showing DL & ATF as the efficacious component causing SB reduction, it was reported as a key mechanism of behaviour change in several qualitative studies. Participants in [69] highlighted the motivational value of being able to view logged data through visual graphics in a website and gain feedback; [70] 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.

**PDC & ATF - 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, as it capitalises on automated sensing technologies and activity detection algorithms. Smartphones and pedometers were the two 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 [40,41,43,71]. 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’ [40,71,72].

As in [66] mentioned above, 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 [24,38,44,46,58,63,73,74]. Participants generally considered the technological monitoring tool very helpful [46,69] and an evidence for organisational investment in staff health [75].

Notably, only six [19,38,51,59,66,74] out of the 25 PDC & ATF had reached the evaluation and implementation phases, five 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 [39]. 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 [41,71]; potential features demanded by users were visual feedback on the health outcomes of sedentary behaviours, accurate and reliable data sources, and the control over the collection and sharing of their data feedback with colleagues [76].

**PDC & SP (JITAI) – 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**’, as well as ‘**JITAI**’ (Just-in-time adaptive intervention) in bracket, to be differentiated from the nine SP interventions that prompted users at fixed times throughout the day [44,47,68,77–80]. 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 [40] 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 [42] conducted a randomised crossover study with audible break prompts delivered from an smartphone application for one week in each of the three
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 [41]. Mukhtar and Belaid [43] 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 [67], user annoyance with the passive prompt approach was also reported [70].

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 [64]. 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 [81].

**CD & PDC & SP - 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 PDC & CD & SP interventions had moved to the evaluation phase [51]. 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. Although there was no significant between-condition differences in prolonged sitting reduction, a 70.5% uptake of the waist-worn activity tracker was encouraging.

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 [45,48], wearables to capture activities and postures [51,82,83], and sensors attached to workstations to infer sedentary time from workstation use time [40,84].
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 [51,85]. Some early studies used mobile networks to send text messages from a server to a mobile phone as a way of prompting users [40,82]. USB and other cable-based connections were often utilised in systems for which portability was not crucial. For instance, [40,82,84,86] 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 [48,87], 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 [72] 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 [88] connected a posture sensing chair to three 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 [48,84], or ambient lights that altered colour [87,89] to reflect user’s sedentary time and reminder 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.

Discussion

Principle results

The present review sought to inform researchers, developers, healthcare professionals and commissioners interested in digital SB interventions for office workers about the research activity in this field, and to identify technological opportunities that could be further exploited.

This paper, first of all, serves as a roadmap that indicates the range and location of the 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 8 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, we observe that the development and piloting work conducted in this field was located across the globe, whereas the evaluation/implementation research was more concentrated in specific countries, usually associated with large national research initiatives (e.g. Australia - ‘Stand up Australia’, ‘Global Corporate Challenge’; the Netherlands - ‘Vitality in Practice’; Spain - ‘Walk@WorkSpain’). Those projects were 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’ - [55,57,62,90,91]; “Vitality in Practice” (VIP) project - [49,92]). In terms of disciplines where research on this topic can be located, we demonstrated the added value of searching for articles outside medical and health sciences databases. Finally, we found many SB reduction elements embedded in interventions targeting other behaviours such as posture correction or PA promotion. Indeed, only 18 interventions in the present review solely targeted SB reduction.

Secondly, this review provides an overview of the current technological landscape in this field, with a novel coding scheme constructed specially for this purpose. 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 in studies reviewed [23,24,44,51,57,62,80,90,91,93] [44,54,73,77], they were seldom integrated with other technological features as part of the intervention delivery system. This may be associated with the following factors.

For one thing, the PDC devices mentioned above were not designed to allow wearers, or even researchers, to have near real-time access to feedback on SB during the study period, either directly on the device itself or via a connected device. This accounted for many studies where participants were asked to wear pedometers for feedback alongside the research data collection devices [44–46]. In these cases, the immediate feedback available to participants was usually limited to overall numeric summaries of PA rather than SB (e.g. overall step count or calorie burnt). More detailed feedback on sedentary bouts collected with validated research devices was usually delivered after
the data collection period, and by a human coach, rather than via an automated system [53,57,80,90,91].

For another, those validated PDC devices were incapable of integration with prompting devices. This would not only prevent JITAI from utilising these validated behavioural data, but limit the potential for more sophisticated analysis of response latency to prompts [47]. In addition, the high price of those research-purposes PDC devices demotivated deployment outside the assessment period (usually 1 week or 5 workdays). This in turn decreased possibility to collect and analyse data continuously throughout the whole study period, which would otherwise yield valuable insights into the process of change, as demonstrated in several studies [40,42,90].

That was why we coded 'Connected Devices' (CD) separately and considered it a very important trend that could potentially catalyse a paradigm shift in the use of data in behaviour change. Not to mention easier incorporation of multiple data sources, CD greatly expands the range of interfaces and media that can be used to convey messages and information to users. We identified exploratory work on developing and piloting ambient displays to deliver break reminders subtly [64,87,89]. 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 are created [48,88] or proposed [81,84] as a creative and pleasant way to persuade users into taking breaks and caring for their own health.

Implications
Several notable research gaps can be identified from Table 5. First 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. To achieve this, collaborations between health intervention designers and computer scientists/engineers need to be fostered in both the academic and industry sectors. To our knowledge, none of the manufacturers of activity monitors identified in this review has provided the protocol to allow sharing of data wirelessly and instantly with third-party applications. While ActiGraph wGT3x-BT and ActiGraph GT9X Link are now powered with Bluetooth connectivity, the communication is restricted to the company’s own suite of mobile applications. What would really benefit the field is the provision of an Application Programming Interface (API) to allow easy access to data collected with those validated devices in real-time or near real-time. This will enable rapid development and deployment of JITAIIs for SB reduction.

Another notable blank spot in Table 5 is the lack of research on scheduled prompts (SP) beyond the piloting/feasibility phase. This line of research is worth pursuing, as 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)[39]. Additionally, with the decreasing cost of embedded computing and electronics, more novel forms of digital media have emerged to present alert users in a subtle yet effective way, by
embedding information in the physical environment and utilising sensory and peripheral channels for communication (e.g. ambient light, or texture, shape and colour of physical artefacts) [94]. Considering the numerous innovative break prompting installations that have been developed and piloted in engineering, computing and design fields, efforts could also be directed to moving them to the next phase of evaluation with a more rigorous study design.

Finally, researchers from all disciplines can familiarize themselves with the MRC guidance and start following a phased approach to conducting and reporting the development and evaluation research on their interventions. More emphasis should also be placed on process evaluation and reporting users’ perspectives on the technology-delivered interventions in addition to other design-related outcomes.

**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 we did not compare or synthesize the behaviour change outcomes across interventions. In addition, our 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 could have been coded in more details. But we deemed it unnecessary, because a scoping review specifically on characteristics of SB and PA monitors [95] was published during our data extraction phase.

**Conclusion**
This review demonstrates the prevalent and diverse use of digital technologies in SB interventions targeting office workers. While the use of screen-based platforms to exchange information and mediate organisational support and social influences is well-established, SB research drawing on novel media, such as interactive physical objects and environment, is still in its infancy. In addition, the most validated and reliable research-purposed activity monitors available in the market have not been designed for easy integration with other devices. Behaviour change researchers may consider collaborating with both academic computer scientists and engineers from the private sector to exploit wireless connectivity between devices to make interventions more adaptive to the user’s current state and context. Opportunities also exist to improve the utility of future research by following the MRC framework on development and evaluation of complex interventions.

**Acknowledgements**
This research is supported by supported by the Horizon Centre for Doctoral Training at the University of Nottingham (RCUK Grant No. EP/L015463/1) and Unilever UK Ltd. (www.unilever.co.uk/).

**Conflicts of Interest**
None declared.

**Abbreviations**
BCI: behaviour change intervention
Reference


23. Evans RE, Fawole HO, Sheriff SA, Dall PM, Grant PM, Ryan CG. Point-of-choice


25. Gordon A. A Theory-based Pilot Study to Decrease Sitting Time in the Workplace [Internet]. Arizona State University; 2013 [cited 2016 Apr 29]. Available from: https://repository.asu.edu/items/18687


49. Coffeng JK, Hendriksen IJ, Duijts SF, Proper KI, van Mechelen W, Boot CRL. The development of the Be Active & Relax “Vitality in Practice” (VIP) project and design of an RCT to reduce the need for recovery in office employees. BMC Public Health [Internet] 2012;12(1):592. PMID:22852835

50. Coffeng JK, Boot CRL, Duijts SFA, Twisk JWR, Van Mechelen W, Hendriksen IJM. Effectiveness of a worksite social & physical environment intervention on need for recovery, physical activity and relaxation; results of a randomized controlled


54. van Berkel J, Proper KI, Boot CR, Bongers PM, van der Beek AJ. Mindful “Vitality in Practice”: an intervention to improve the work engagement and energy balance among workers; the development and design of the randomised controlled trial. BMC Public Health [Internet] BioMed Central Ltd; 2011;11(1):736. PMID:21951433


61. van Berkel J, Boot CRL, Proper KI, Bongers PM, van der Beek AJ. Effectiveness of a


73. Parry S, Straker L, Gilson ND, Smith AJ. Participatory workplace interventions can


