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Iterative four-phase development of a theory-based digital behaviour change intervention to reduce occupational sedentary behaviour

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Abstract

Introduction: As high amounts of occupational sitting have been associated with negative health consequences, designing workplace interventions to reduce sedentary behaviour (SB) is of public health interest. Digital technology may serve as a cost-effective and scalable platform to deliver such an intervention. This study describes the iterative development of a theory-based, digital behaviour change intervention to reduce occupational SB.

Methods: The behaviour change wheel and The Behaviour Change Technique Taxonomy were used to guide the intervention design process and form a basis for selecting the intervention components. The development process consisted of four phases: phase 1 – preliminary research, phase 2 – consensus workshops, phase 3 – white boarding and phase 4 – usability testing.

Results: The process led to the development and refinement of a smartphone application – Worktivity. The core component was self-monitoring and feedback of SB at work, complemented by additional features focusing on goal setting, prompts and reminders to break up prolonged periods of sitting, and educational facts and tips. Key features of the app included simple data entry and personalisation based on each individual's self-reported sitting time. Results from the 'think-aloud' interviews ($n=5$) suggest Worktivity was well accepted and that users were positive about its features.

Conclusion: This study led to the development of Worktivity, a theory-based and user-informed mobile app intervention to reduce occupational SB. It is the first app of its kind developed with the primary aim of reducing occupational SB using digital self-monitoring. This paper provides a template to guide others in the development and evaluation of technology-supported behaviour change interventions.

Keywords

Behaviour change, sedentary behaviour, office work, health technology

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Introduction

Office work is generally characterised by prolonged periods of sitting and contributes significantly to the overall sedentary time of office workers.[1] Sedentary activities have been shown to comprise 65–82% of time at work in industrialised countries,[1–3] with a large proportion (54–77%) of office workers' total daily sitting time occurring during their working day.[2,4,5] This high occupational exposure to sedentary behaviour (SB) has broad implications for population health. Recent systematic reviews report evidence linking SB to all-cause mortality, cardiovascular disease, type 2 diabetes, metabolic syndrome and some cancers.[6–9] Specifically relating to occupational SB, results of other systematic reviews show associations between occupational sitting and body mass index and the prevalence of type 2 diabetes, all-cause mortality and certain cancers.[10–12] Therefore, occupational SB has become an emergent workplace health concern.[13]

The use of digital technology to monitor and improve health is growing in popularity. A recent survey on digital health showed that 75% of consumers in the USA reported technology as being important in managing their health.[14] An increasing number of consumers in England also report that technologies have become more important in managing their health (up from 37% in 2016 to 48% in 2018), with the use of wearables also increasing (up from 22% in 2016 to 31% in 2018).[15] Moreover, the smartphone has become intertwined into our daily lives. A recent UK survey reports that 87% of respondents own or have access to a smartphone.[16] Given the widespread usage of digital health devices, there is great potential for well-designed digital behaviour change interventions (DBCIs) to facilitate positive health behaviour change.

There is evidence to support the use of digital technologies as intervention tools to improve health behaviours. Computer and mobile technologies have been successfully applied to improve diet and physical activity,[17,18] sexual health behaviours,[19] weight management,[20] alcohol reduction[18] and smoking cessation.[21,22] Digital technologies have also been used to reduce SB.[23,24] In a recent systematic review and meta-analysis, interventions using computer, mobile and wearable technologies were shown to reduce SB over the whole day, as well as during working hours.[24] There are many features of DBCIs that make them potentially effective. They can broaden the reach and scale of behaviour change interventions, be highly personalised and deliver information in a way that is engaging and rewarding.[25,26] Research also suggests that technology-based interventions can be cost effective and less labour intensive than face-to-face interventions.[26–29] Although encouraging, the research describing how digital tools can be harnessed to reduce occupational SB is still in its infancy

It has been suggested that digital interventions to reduce occupational SB may be most valuable as a platform to allow behavioural self-monitoring.[30] It also has been reported that existing digital interventions lack theory[31] and that the most promising SB interventions tend to target reducing SB instead of increasing physical activity.[32,33] Systematic reviews have also suggested a dearth of existing theory-informed digital tools that are focused on reducing occupational SB and which allow behavioural self-monitoring,[24,34] further highlighting the need to create a more appropriate digital tool.

There is a need for the methodical development and rigorous evaluation of new, theory-supported, technology-based interventions to reduce occupational SB. However, reporting on the development phases used in creating health-related digital technology is limited.[35] The process of developing effective digital interventions requires numerous decisions that integrate behavioural theory, user testing and technical and practical feasibility considerations, including interventions to address occupational SB.[36–38] The importance of behaviour change theory in digital technologies has been stressed,[26,38] and indeed recommendations on the prevention and management of non-communicable diseases highlight the need for research focused on behaviour change as the core component.[39] Research suggests that Internet-based interventions developed with more extensive use of theory are associated with larger effect sizes than those without.[40] Despite the clear recommendations for use of theory, many digital interventions lack a theoretical basis to improve health behaviours and reduce occupational sitting.[31,41–44]

To promote engagement with digital interventions, a 'user-centred' approach is essential.[45] User-centred design (UCD) is an iterative design process in which designers involve users throughout the design process.[46] Incorporating UCD principles ensures that interventions are responsive to users' needs and preferences, and are designed 'from the ground up' rather than based on developers' preconceptions or rigid procurement briefs.[45,47] This study describes the process undertaken to design and develop a digital DBCI to reduce occupational SB in office workers.

Development process and outcomes

The development process reported in this paper was conducted in line with the Medical Research Council guidelines for the development and evaluation of complex interventions.[48] It involved the preliminary phases of intervention development as outlined in Table 1. The process was managed by a collaborative planning and

Table 1. Schematic of development process.

Phase	Activity	Outcome
1. Preliminary research	(a) Systematic review and meta-analysis (b) Focus groups with target end users and stakeholders (c) Review of BCW and BCTTv1	Understanding the behaviour and what needs to change
2. Consensus workshops	(d) Additional review of wider/relevant literature (e) Mind mapping (f) Application of APEASE (g) Selecting app components	Identify intervention options and content
3. White boarding	(h) Interface design principles to design application software (i) Sketches (j) Wireframes	Design of prototype
4. Usability testing	(k) 'Think-aloud' interviews and iterative refinement	Worktivity app

BCW: Behaviour Change Wheel[49]; BCTTv1: Behaviour Change Technique Taxonomy version 1[50]; APEASE: Acceptability, Practicability, Effectiveness and cost-effectiveness, Affordability, Safety/side-effects, Equity.[51]

design team of six members, including behaviour change researchers, SB and physical activity experts and computer scientists. The process was iterative and involved regular development team meetings, repeated reviews and multiple discussions to resolve issues as they arose. Excluding the time it took to conduct the systematic review and focus group preliminary work (activities (a) and (b), Table 1), the development process lasted approximately three months.

Phase 1: preliminary research

Initially, a systematic review and meta-analysis of technology-enhanced interventions targeting SB reduction was conducted.[24] Results from this indicated that it may be possible to intervene and reduce occupational SB by approximately 40 minutes per day using technology-enhanced interventions. This work was followed by a focus group study exploring the views of office workers, their managers and company board members on barriers, facilitators and strategies to reduce SB at work.[30] Qualitative analysis revealed that technology was generally seen to be a useful tool, with particular valuable in providing prompts and as a platform to allow behavioural self-monitoring via smartphone apps. These results informed the subsequent phases of the process as detailed in Table 1.

The behaviour change wheel (BCW)[49] and the Behaviour Change Technique Taxonomy (BCTTv1)[50] were used to guide the development process and to form a basis for selecting the intervention components. The BCW provides a structured, theoretical framework for designing behaviour change interventions and strategies.[51] The model has been successfully applied as a framework to develop DBCIs.[52,53] The BCTTv1 is an extensive hierarchically organised taxonomy of 93 distinct behaviour change techniques (BCT) which is linked to the BCW, but it gives more specific description of the intervention options in the BCW and provides a way of characterising the content of behaviour change interventions at a finer-grain level than the BCW does.[26,54] This approach was chosen to promote a systematic and comprehensive analysis of the available options using behaviour change theory and the available evidence.[54] The key benefit of using this framework was to allow the designers to be comprehensive in considering all options, to intervene and then to select systematically those that were most promising for the context.[51]

Phase 1 outcomes. Prolonged occupational SB was established as the problem to be addressed due to the negative health consequences associated with prolonged sitting.[8,10] Reducing total time spent in SB at work was therefore established as the primary target behaviour of the intervention, achieved through reductions in time spent sitting, number of prolonged sitting bouts, increases in interruptions to sitting and transitions from sitting to standing. Individual desk-based office workers were identified as the target population.

The needs and preferences of the target population and key stakeholders were identified in a previous study through focus groups discussions with office workers, managers and board level employees.[24] Their identified needs and preferences, as well as practical barriers and facilitators to reducing SB at work, were used to frame the intervention and guide the proposed approaches and content. Specifically, we focused on a personalised approach, minimising impact on work tasks, highlighting opportunities to break SB during the workday so as not to compromise productivity, and educating employees regarding the negative health consequences associated with prolonged SB. Their preferences for digital interventions with low user burden, delivered in a personalised, accurate and non-patronising fashion were also considered.

Phase 2a: consensus on strategy type

Consensus workshops were held with the research team to amalgamate and discuss findings of phase 1, gain expert opinions and draw upon evidence from existing literature. These lasted approximately one hour. Mind-mapping sessions were held as part of these workshops with members of the design team to define the requirements of the DBCI. The APEASE criteria (Acceptability, Practicability, Effectiveness and cost-effectiveness, Affordability, Safety/side-effects, Equity) were used when making decisions about which technology strategy would be most appropriate.[54] Decisions were made based on consensus amongst the group.

Phase 2a outcomes. In our previous work, digital reminders/prompts and self-monitoring of SB were identified as possible intervention strategies.[24,30] The research team considered available technologies that could be used to facilitate these strategies in the workplace.

- Digital reminders/prompts. Websites and computer-based prompts were not selected, as they are not portable. Portability was deemed to be an important factor, as a portable platform allowed users to interact with the intervention when they were away from their desk (e.g. off site or in a meeting).
- Self-monitoring of SB. The most promising SB interventions tend to target reducing SB instead of increasing physical activity.[32,33] As wearable or mobile app-based activity trackers (e.g. Fitbit, Apple Health App) use an accelerometer to measure movement (i.e. PA and/or step counts), they do not accurately capture non-movement (i.e. SB and/or posture) because they use low step counts per minute as a proxy for SB.[55] A recent scoping review of devices for self-monitoring sedentary time highlighted that there were only a small number of devices capable of providing SB feedback, none of which were originally designed to measure SB.[56] While inclinometers that can measure SB and posture are available (e.g. ActivPAL™), these are designed for research purposes, lack a user-friendly interface and are not appropriate for everyday consumer use.

The research team concluded that a smartphone app that allows individuals to monitor their SB by self-report would overcome the device-based measurement issues mentioned above. Mobile phones are ubiquitous, portable, small and light.[57] In addition, mobile apps to reduce SB were deemed potentially acceptable in our previous qualitative work.[30] The research team also had expertise in app development. Therefore, a smartphone app was the chosen technology strategy.

Phase 2b: Consensus on intervention functions

The selection of intervention functions for inclusion in the app components was informed by: (a) the intervention functions of the BCW framework;[54] (b) a review of existing commercially available smartphone apps that focussed on changing health behaviours, specifically a reduction in SB; (c) the expert discussion and consensus-building workshops on 'best bets', with decisions informed by knowledge of all the experts on the design team as well as the current evidence, including the results from the systematic review and meta-analysis, and focus group results as part of the preliminary phase; and (d) expert advice on how feasible, in terms of computer programming, each possible intervention function would be.

Phase 2b outcomes. Out of a possible nine intervention functions within the BCW, the team identified five which were suitable to be incorporated into app components to reduce SB. These were: education, persuasion, enablement, training and environmental restructuring. These five intervention functions were addressed by selecting four specific app components as shown in Table 2. The selection of the BCTs appropriate for each function were based upon guidance provided by Michie et al.[54]

The culmination of these stages resulted in an app consisting of four key components: (a) self-monitoring and feedback, (b) prompts and reminders, (c) goal setting and monitoring and (d) educational facts and tips.

(a) Self-monitoring and feedback. Self-monitoring and feedback was deemed to be the key component of the intervention, as it has previously been shown to be

Table 2. App components aligned to the BCW.

Component	Intervention function	Behaviour change techniques[a]
Self-monitoring and feedback	Education	2.2. Feedback on behaviour
	Persuasion	2.3. Self-monitoring of behaviour
	Enablement	2.2. Feedback on behaviour
		2.3. Self-monitoring of behaviour
Goal setting	Enablement	1.1. Goal-setting (behaviour)
		1.4. Action planning
Prompts to break sitting	Environmental restructuring	7.1. Prompts/cues
	Enablement	7.1. Prompts/cues
Educational facts and tips	Education	5.1. Information about health consequences
	Training	4.1. Instruction on how to perform the behaviour

[a]These BCTs and their numbers are taken directly from the BCTTv1.[50]

effective in a similar community based 'sit-less' intervention. Using a digital activity tracker and providing feedback on percentage time spent sedentary was the most important factor in supporting behaviour change.[58] Furthermore, a recent systematic review exploring interventions with potential to reduce sedentary time in adults recommended that new interventions should be developed around technologies that allow people to monitor their SB.[33]

The BCTs selected to be used within this app feature were 'self-monitoring of behaviour' and 'feedback on behaviour'. The concept of 'self-monitoring' is comprised of two major attributes: (a) awareness of bodily symptoms, sensations, daily activities and cognitive processes; and (b) measurements, recordings or observations that inform cognition and provide information action.[59] Self-monitoring can make the monitored activities more salient to the user.[60] 'Feedback' allows the rate of progress towards a goal to be determined and augments the effects of self-monitoring.[61–64]

Self-monitoring has been shown to be a particularly promising BCT in interventions to reduce SB.[65] Personalised feedback has also been shown to be effective in digital weight-loss interventions and has been suggested as an effective component within technology-based behaviour change interventions.[66] Self-monitoring and feedback also allows the intervention to be tailored to the individual. Tailoring interventions is crucial, as people tend to stop using technologies that do not correspond with their daily lives.[67] Hence, tailoring to the user's needs and preferences can improve engagement.[54]

(b) Prompts and reminders to break sitting. Prompts and reminders were selected as an app feature, as periodic prompts have been shown to yield positive results in health behaviour interventions to encourage and maintain behaviour change alone and as part of a multi-component intervention.[68] Prompts and reminders were also identified in our systematic review and focus group research[24,30] as possible intervention strategies to reduce occupational SB. The specific BCT included in this section was 'prompts and cues'. This BCT was selected, as it was identified in an intervention description where digital prompts to break sitting were shown to be superior to education alone in reducing occupational SB.[69]

(c) Goal setting and monitoring. Goal setting was added to the intervention components based on the recommendation of its use in behaviour change interventions by the National Institute for Health and Care Excellence.[70] It was also selected due to its current evidence base in behaviour change interventions. Having a goal serves as a directive and energising function, and can positively affect persistence and action.[71] Results from a recent meta-analysis also suggest that monitoring goals is an effective self-regulation strategy.[68,72] 'Goal setting (behaviour)' was included as the main BCT for this intervention component. This was selected, as it was identified as one of the most common BCTs in recent systematic reviews.[24,32] Action planning was also included as a BCT, as it has been shown to be effective in changing workplace sitting.[73] The goal setting and action planning relates to reducing daily occupational sitting time.

(d) Educational facts and tips. Educational facts and tips were included based upon the findings from our qualitative study[30] which identified a lack of knowledge of the negative health effects of prolonged SB. It cannot be assumed that all members of the public are aware that sitting could be detrimental to their health, as it an emerging area of research.[74] It was also identified in a systematic review that despite education being identified as one of the most promising BCTs, surprisingly few SB reduction interventions seek to motivate participants through information provision or education.[32] The facts and tips were designed upon the basis of two BCTs – 'instruction on how to perform the behaviour' and 'information about health consequences' – to give health advice and tips to encourage less SB at work. Both of these BCTs have been identified as promising in reducing SB.[32]

Phase 3: white boarding

Once the intervention content and BCTs were identified, potential versions of an app were discussed amongst the whole team. An ideation session was held with three members of the research team (A.S., M.G.C. and C.N.), and from that, wireframes were drawn up (A.S. and M.G.C.). These sketches presented a schematic of the main content and a basic design structure.

The app was designed based on principles from 10 Usability Heuristics for User Interface Design,[75] Eight Golden Rules of Interface Design[76] and Human Interface Guidelines.[77] Briefly, these principles suggest that the app should: use consistent and familiar terminology, offer informative feedback, keep displays simple and minimalistic, be visually appealing and provide clear engaging feedback.

Phase 3 outcomes. An intervention specification document detailing the design brief was drawn up by the team, which was then used to create a high fidelity functional prototype. The app was then constructed using the Xamarin cross-platform development tool (Microsoft Corp., Redmond, CA).

As the intervention relied heavily on self-reporting of SB, it was important that data entry was simple. A survey of health app use among US mobile phone owners showed that approximately half of app users stopped using the app, with high data entry burden mentioned as one of the primary reasons.[78] Data entry was achieved by moving a fixed-width slider across the screen until the desired value (time spent sitting within the previous hour) was presented (Figure 1). We based the data entry methods on a previous study which implemented the same data entry mechanism with success.[79]

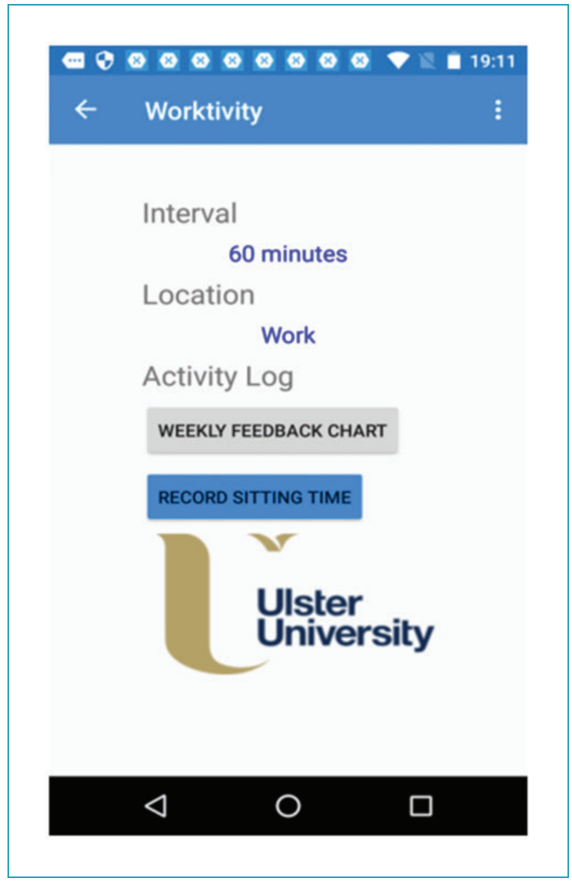

Figure 1. Home screen.

To promote engagement further, the prompts to break sitting were designed to be non-punitive or didactic, as this can affect the user experience.[80] The use of push notifications was also used to increase user engagement. These were used to remind the user to engage with the app and, once interacted with, provided a quick 'shortcut' to the app's self-monitoring section, lessening user burden. Functional prototypes were tested iteratively in-house during development for platform stability and bugs, and were amended as required.

Phase 4: usability testing

Usability is one of the main barriers to the adoption of mobile health systems,[81] particularly smartphones, whose small displays present particular usability challenges.[82] Therefore, evaluating usability was an important phase of the development process. 'Think aloud' is a research method in which participants speak aloud any words in their mind as they complete a task, or recall thoughts immediately following completion of that task.[83,84] It can be of high value in evaluating a system's design on usability flaws and is therefore frequently used to gather information about a system's usability with potential end users.[85] It can reveal how intervention techniques are interpreted by the intended recipients, help to ensure the language used is understandable and give insight into what users think of the graphic design, navigation and functionality.[64,86] It is an industry standard approach in software development,[78] and has been used in similar studies to assess usability in the development of digital interventions.[86,87]

In order to assess the usability of the app, a 'think-aloud' analysis was undertaken.[88] Ethical approval was obtained from Ulster University School of Sport Research Ethics Filter Committee. A convenience sample of five desk-based office workers (colleagues from the university; 100% female) was recruited. This number was selected, as after five test subjects, 77–85% of problems can be detected.[89] Participants were given participant information sheets and provided written informed consent before the study commenced. All sessions were one-on-one and conducted face-to-face by A.S. These took place in a private space within Ulster University in September 2017, and each session lasted 20–26 minutes.

Participants were given a time-compressed version of the functional app prototype, whereby one hour was compressed to two minutes. This was to represent a compressed eight-hour workday, as it was not feasible to test the app over the entire course of a workday. Therefore, the users tested the app over a 16-minute period. The participants were requested to continue with their work tasks and to interact with the app as prompted. Participants were requested to verbalise what they were thinking about, looking at, doing and feeling throughout the process of engaging with the app. After the compressed workday ended, participants were asked to provide information on how they liked the app, difficulties encountered and suggestions for improvement. The exact questions are available in Supplemental File 1.

The interviews were audio-recorded, transcribed verbatim and analysed using thematic analysis.[90] This method has been used previously to analyse usability studies of smartphone apps.[80,91] The transcripts were read multiple times to familiarise content. Line-by-line coding was then undertaken to assign conceptual labels to relevant excerpts of the data set. These codes were then used to devise an initial set of themes which were revised iteratively before producing a final thematic framework. Pertinent quotes were selected to characterise each theme.

Phase 4 outcomes. Two major themes emerged from the data: (a) app design and (b) content. These were both considered important elements influencing usability.

(a) App design. The app design theme reflected participants' need for simple data entry systems which did not distract the user from their work.

> I found the record sitting time very easy to use in that you literally just drag for as many minutes as you need and then save it, do you know, if you were doing that a few times throughout the day it would be very easily done. (Participant 1)

Most participants deemed the slider mechanism as a simple and efficient method of data entry, although one participant mentioned slight trouble with the touch screen when attempting to use the slider.

> Just sometimes when you're trying to slide your finger up for your time it kinda does get, it's hard to get the slidey thing going which was a bit kind of frustrating. (Participant 4)

The design of the prompts, their delivery and the repeated need for data entry were flagged by participants as potentially disruptive when workload was high.

> If you were really sort of deep in to what you were doing, it's very easy then to allow something like this to distract you. (Participant 5)

Participants reported that the app was easy to operate and they valued the quick and intuitive navigation afforded by the app.

> The actual app itself is fairly easy to navigate. (Participant 2)

The visual feedback graphs and goal-setting displays were welcomed by users. However, most participants had issues interpreting the information due to the units not being displayed on the graphs and an inadequate explanation of the goal setting display.

> There's just 5 stars [in the goal setting section], so I don't really know what that means. (Participant 4)

(b) Content. The content of the app was seen as useful, educational and informative. One participant felt the app unsuitable for her at work, as she preferred to sit whilst at work.

> I'm being more productive while I'm sitting, so I'm going to sit. It's a little bit disruptive, sitting and standing. (Participant 2)

The other participants found the content to be thought provoking and motivating.

> It [the app] would actually make you think yea I need to get up. (Participant 5)

Participants generally liked how the app was not overly complicated and did not have an excessive number of features. The low app content was praised by users, as they felt too much content may be distracting and would overwhelm them with choice.

> I think over all it gives you everything you would need and if anything more, I think would nearly distract you from actually doing your work, you know it has everything you need, in a compact format. (Participant 1)

They used and understood the app without major issues; although some participants were unsure about exactly what they should do when they were prompted to reduce SB and how long they should reduce their SB for.

> Do I have to wait until the app tells me to sit down again? (Participant 1)

Overall, participants were very positive about the app. They generally felt that the app was well designed and that the content was relevant. Participants expressed positive interest in the app.

> It is clear and easy to use, it's not too complicated. It doesn't have anything too, what's the word I'm looking for, irrelevant. It's all relevant and brief, which is good. (Participant 3)

> Yea I think it's lovely. It's a nice wee app to use. It's very easy. It's good. (Participant 1)

Participants had suggestions to improve the overall user experience. The visual display of feedback charts could be improved by adding units to the chart. They suggested that a short description of how the goal-setting feature worked and what the display represented would be beneficial. It was noted that the prompts to log sitting were very frequent which was deemed to be 'annoying'. This was later identified as a bug in the system; when users were entering the data, another prompt to enter data was sent to the phone.

Based on these findings, the interface of the app was adapted, and several modifications were made to correct errors. Units (minutes per day) were added to the feedback chart, and a description of the goal setting feature was added. The issue noted by one user where the slider was difficult to slide across the screen was not fixed, as the slider feature was generally well liked by the other participants. The issue whereby users were unsure how long to break sitting by and what exactly to do with their time was also not dealt with in app amendments. This was because the design team did not want to impose tight rules on how to change behaviour and instead wanted users to be free to make their own SB reduction choices. The new version of the app went through thorough in-house testing by the research team before the final version was released.

Phase 5: final product

The research team named the resulting smartphone app 'Worktivity': a portmanteau of the words 'work' and 'activity'. The core component of the mobile app was self-monitoring and feedback of SB at work. This was complemented by additional features focusing on goal setting, prompts to break sitting and educational facts and tips. Screenshots of these features are available in Figures 2–5.

Outcomes of final product

Figure 2 shows the home screen of Worktivity, where users can record sitting time and view their activity log.

Prompts to break sitting and self-reporting/ monitoring and feedback

The app prompts the user to self-monitor sitting time at work by asking 'How long have you spent sitting within the last 60 minutes?' each hour over the eight-hour workday (Figure 1). The first prompt to self-report appears after the first hour of work each day (e.g. 10:00am), and the last self-monitoring prompt occurs just as they are scheduled to leave work (e.g. 5:00pm). Data entry takes place in the form of a user-friendly horizontal slider, and participants respond to the question by moving the slider to the number of minutes they reported to have spent sitting in the last hour. After five minutes, if no response is entered, a reminder is delivered. Based upon the results of the personalised goal set by the user (discussed below) and their self-monitoring input, if their sitting time is too high, a prompt appears on the screen with advice to break their sitting. This prompt is in the form of a visual screen prompt, vibration and an auditory alarm. Participants can set the phone to their preference of alert but were advised to keep the device's default auditory and vibratory prompts activated.

The app also provides a feedback progress report with graphical displays of time spent sitting and time spent in activity each day (Figure 3). These reports are based on the self-reported data entry. Users can access

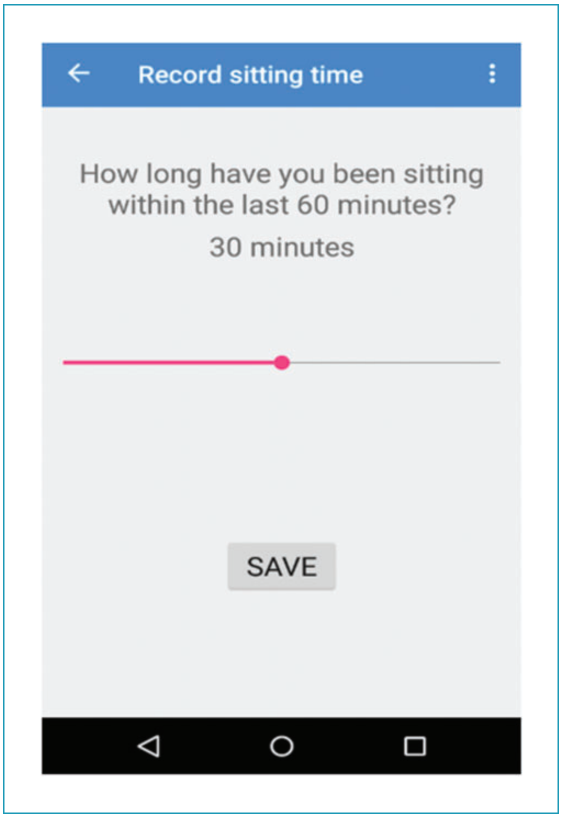

Figure 2. Record sitting time.

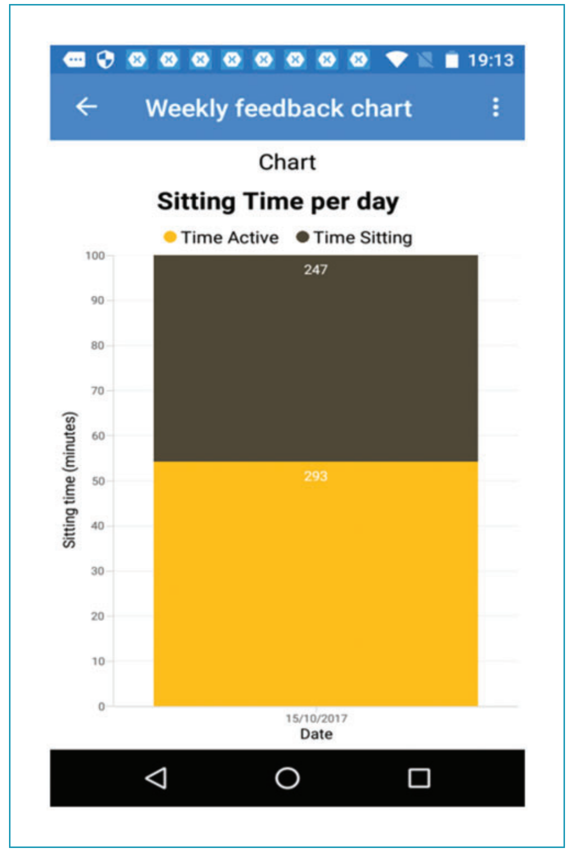

Figure 3. Feedback graph.

this feedback at any time, and it is possible for users to view their historical data.

Goal setting

The apps goal-setting feature allows users to set goals to reduce SB at work. The goal chosen reflects by how much time each day the user wishes to reduce their SB. The app then calculates by how much time the user must reduce their sitting each hour of the workday in order to meet their goal. For example, if a participant sets a two-hour (120-minute reduction) per day 'sit-less' goal, the app calculated how much time they need to reduce their sitting by each hour over an eight-hour working day (120/8 = 15 minutes every hour). This means that a participant has to spend at least 15 minutes of each hour standing or moving in order to reach their goal. Therefore, when self-monitoring their SB, if the user reports that they sat for 46 minutes or more in the previous hour, they receive an automated message to stand and/or move. The progress made towards reaching their goal each day is displayed in the form of a goal visualisation section. This allows users to check if they had met their 'sit-less' goals. Five stars are presented on the screen, as recommended by Hartin et al.[79] as a variant of a points-earning system to encourage behaviour change. The use of a familiar five-star rating system is also in keeping with the guidelines for optimising user interface design. As the user meets their hourly goals, the stars change from white to blue to represent how often they meet their goal each day (Figure 4). All recorded values in the logs are normalised to within a range of 0–5 in relation to the goal,[79] that is, if a user meets every hourly goal over an eight-hour workday, five stars are shaded blue, but if a user meets four of eight hourly goals, then 2.5 stars are shaded blue.

Educational fact and tip

All participants received an educational fact and tip at the end of each day when they entered their last data entry report for that day (Figure 5). These included a visual graphic with a snippet of health education advice and a practical tip to reduce their SB at work. The educational fact and tip was selected at random from a pool of 50 stored in the app (Supplemental File 2).

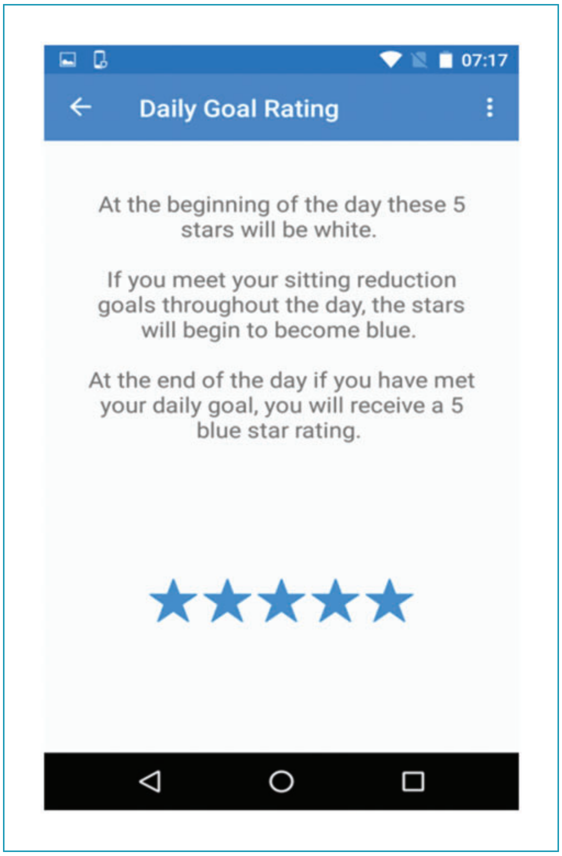

Figure 4. Daily goal rating.

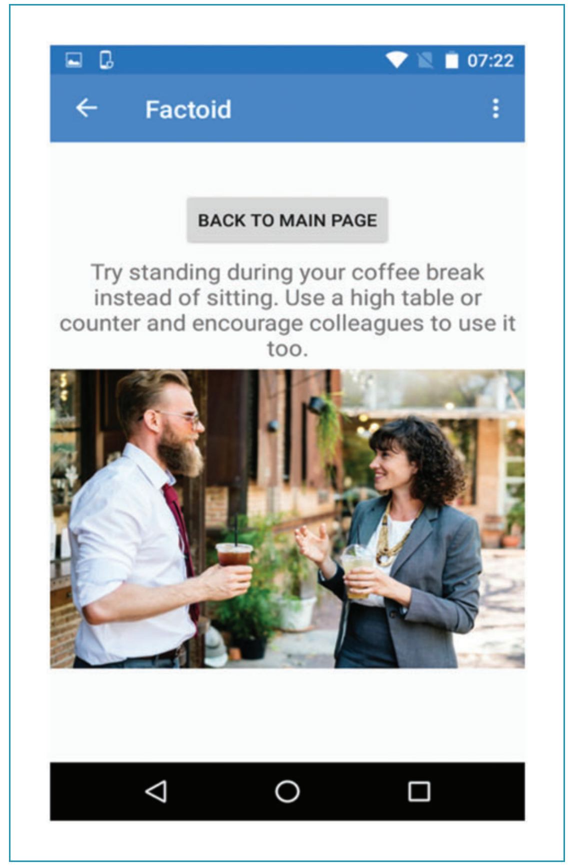

Figure 5. Educational fact/tip.

Discussion

The use of app interventions to reduce SB is in its infancy. Yet, findings appear promising. Results of a recent systematic review showed that only one randomised controlled trial (RCT) used a mobile app as an optional part of a successful intervention to reduce SB.[24] Two other studies (non-RCT) had delivered SB reduction interventions showing successful reductions in SB via apps.[92,93] However, the main focus in both these studies was to encourage participants to engage in PA, rather than specifically to reduce their SB. In addition, many digital health interventions tend to be developed rapidly for commercial purposes and lack scientific theoretical basis.[41–44,94] Worktivity is a novel, theory-based intervention, delivered via a user-informed mobile app designed to reduce occupational SB. Its development was inspired by the growing health concerns regarding prolonged sitting in office workers,[8,10] the potential for technology to intervene,[9] plus the lack of existing theoretically based app interventions,[41–44] specifically targeting SB reduction.

Worktivity's step-by-step development and refinement in line with the BCW framework drew upon findings from preliminary research, consensus workshops, white boarding and usability testing in order to address the issues mentioned above. This formative and iterative development process ensured the content and format of Worktivity was developed to meet the needs of end users and allowed for issues of acceptability and credibility to be addressed prior to its implementation. Worktivity is centred on the key component of self-monitoring SB. The data obtained are then used to deliver individually tailored behavioural prompts and feedback to office workers to help them modify their SB in real time. Educational facts and tips were also delivered to encourage behaviour change. Self-monitoring has been used successfully within other app-based interventions targeting health behaviours, for example drug and alcohol use,[95] diabetes prevention in at-risk adults[96] and weight loss and vegetable consumption.[97] Educational features have also been successfully incorporated into apps targeting health behaviours such as smoking cessation,[98] sun exposure[99] and life-style factors associated with stress urinary incontinence.[100]

Usability is one of the main barriers to the adoption of mobile health systems.[81] Therefore, it is important that apps developed for behaviour change research purposes match the usability and sophistication that users expect from other 'real-world' apps.[101] Furthermore, digital tools will likely be rejected by users if they are not perceived to have any user benefit or if they have usability problems.[102] It has also been suggested that app usability is closely related to engagement, whereby positive experiences of usability can entice users to engage more with the app.[103] Based on the findings of the 'think-aloud' interviews, Worktivity was generally deemed to be a well-accepted tool, and users were positive about the app features.

Amongst the strengths of this work is the collaborative design team involved. Efficient relationships between a multidisciplinary team including behavioural scientists and computer scientists are recognised as being essential for the success of a DBCI.[26] These interdisciplinary collaborations are vital for achieving sustainable growth in the field of digital health.[104] The benefits of using of the BCW as a development framework allowed us to recognise that the target behaviour can in principle arise from combinations of any of the components of the behaviour system.[49] This framework was considered over others such as the Intervention Mapping Protocol[105] which aims to map behaviour on to its 'theoretical determinants' in order to identify potential levers for change.[49] This paper also includes a detailed report of the intervention development process, usability evaluations and an in-depth description of the final intervention components. There has been a call for intervention developers to publish processes and outcomes from their development of digital interventions.[106] Currently, Worktivity is only designed to be used in the occupational setting. However, it would be possible to modify the content (e.g. prompts, educational facts and tips) and functionality for use in other domains. Sharing these processes will provide design teams with an enhanced grounding of how to use technology to engage populations better in adopting and maintaining health behaviours[35] and allows for continued learning to improve the quality of interventions.[106] Therefore, the development processes used to design Worktivity may be useful to other digital behaviour change researchers.

A limitation of the 'think-aloud' usability study concerns the representativeness of the sample. The purposive recruitment method used meant the sample lacked heterogeneity, and consisted of only female employees. Other demographic information was not collected at the time and therefore cannot be commented on. The sample was small ($N = 5$). However, 'think-aloud' studies can be performed with small numbers of participants. It has been noted that after five test subjects, 77–85% of problems can be detected.[89] It has also been suggested that some participants may find it difficult to generate 'think-aloud' interviews while carrying out a new task or a task that involves a lot of cognitive processing.[107] Therefore, the participants were asked after using the app for any additional comments and suggestions to improve the app. Another limitation to this study is that the 'think aloud' analysis was undertaken with a compressed version of the Worktivity app and not the full working version. Additionally, the app's key component is hinged around self-monitoring of occupational SB. This input may be subject to recall bias and, moreover, will only be available at the times that users volunteer them.[25] In an attempt to address this, Worktivity delivers a reminder to log sitting if a log is not completed. To address recall bias, the users are only asked to recall time spent sitting over the last 60 minutes, which was deemed by the research team to be an appropriate time frame for accurate recall. These limitations further highlight the need for tools specifically to measure and provide feedback on SB in real time. It must also be acknowledged that although UCD principles were incorporated, the end users were not involved directly in deciding on the app content and input from end users through other means.

Conclusion

In conclusion, the development of Worktivity was informed by a systematic application of behaviour change theory, scientific evidence, end user and stakeholder input, computer science and expert consensus. These processes follow a best practice approach to app development.[96] The resulting app is a theory-driven, user-informed mobile app that provides behavioural support to office workers to reduce SB, incorporating carefully considered strategies to increase user engagement. The processes described here should help guide those wishing to develop a theory-based app intervention targeting a particular behaviour. It should also assist those involved in workplace health to consider low-burden digital strategies for reducing workplace SB. Further research exploring the feasibility of using Worktivity to promote SB reductions at work is warranted.

To the authors' knowledge, this is the first app specifically designed for office workers to reduce their SB by delivering tailored feedback on SB and not inactivity in an almost real-time manner. This research also adds to the literature by describing the rigorous design and development of methodology which may prove useful to other digital behaviour change intervention developers.

Contributorship: A.S., M.M., J.M., S.M.D. and C.N. researched literature and conceived the study. A.S. was involved in protocol development, gaining ethical approval, patient recruitment and data analysis. C.N. provided the personnel, equipment and hardware to develop and use

Worktivity. M.G.C. coded and refined the app Worktivity. A. S. wrote the first draft of the manuscript. All authors reviewed and edited the manuscript and approved the final version of the manuscript.

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