GetAMoveOn Network

Leveraging Technology to Enable Mobility and Transform Health

Sedentary Behaviour and Physical Activity Interventions in Older Adults using Digital Technologies with Special Emphasis on Just-In-Time Adaptive Interventions (JITAIs)

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SEDENTARY BEHAVIOUR AND PHYSICAL ACTIVITY INTERVENTIONS IN OLDER ADULTS USING DIGITAL TECHNOLOGIES WITH SPECIAL EMPHASIS ON JUST-IN-TIME ADAPTIVE INTERVENTIONS (JITAIS)

Background: the GetAMoveOn Network+

The GetAMoveOn Network is an interdisciplinary UK community that is addressing the EPSRC Grand Challenge of transforming community health and care through the delivery of tested technologies that promote wellbeing by providing timely, individualised feedback that encourage appropriate activities. We are focusing on movement as a locus for health: it is our test case as it drives so many other benefits that are of value: economically, socially and culturally.

When we move more, we become smarter; as we become stronger, chronic pain decreases. Greater movement, especially in social contexts, improves collaboration. As we move, not only do we reduce stress: we improve our capacity to handle stressful situations and to see more options for creative new solutions. Movement enhances both strength and stamina, improves bone mineral density and balance, reducing incidence of falling and associated hip injuries (causes of death in the elderly). Movement complements other functions, from assisting with sleep and therefore memory and cognition, to helping with diet and associated hormones - improving insulin sensitivity and balancing cortisol. There are recent studies showing benefits of movement related to dementia. And yet, physical inactivity is the fourth leading cause of death worldwide; sedentarism has been called the "new smoking". Meanwhile costs to UK GDP from sedentarism and associated disease are increasing - from sick days lost to work, to elders losing mobility and having to move into care homes.

We have designed ourselves into our sedentarism: sitting during our commute, at desks while we work, and at home on the sofa. There is a critical need to design ourselves back into the natural effects of health accrued simply by moving more. We need solutions that will help build both the evidence and the experience that movement can enhance and benefit people's lives.

New technologies are transforming our ability to capture lifestyle data on individuals in real time. Consumer technologies such as step counters and wifi scales are the tip of an iceberg - research programmes worldwide are proposing lifestyle data capture from devices ranging from video cameras to electricity meters to wearables. Meanwhile pervasive connectivity allows that data to be transmitted, processed through powerful machine learning tools and provided back to people in a heartbeat. While we understand the potential technologies, we do not yet know how to leverage the technology effectively to support transformative health.

Current approaches in ehealth generally only reach a small part of the population that is already interested in fitness, personal data capture, or both. Their uptake is, furthermore, of dubious effect as two recent medical reviews have shown. To have a national impact on health and wellbeing, to reduce the crippling burden of long term health conditions and to move healthcare from the clinic to the community, we need to reach everyone, across a range of abilities and aspirations. We need to connect the potential of the technology with the potential of people and realise the benefits of a healthy, brilliant, population.

Realising this potential requires research on novel technical solutions, supported by theories from sports and health sciences on blending appropriate movement strategies for particular performance aspirations to behavioural and cognitive sciences on ways to engage people to make effective and meaningful progress. We need to understand what measures are appropriate not just to evaluate progress, but to guide it and adapt to it. To have meaningful impact across these dimensions we need to combine a range of expertise including sensor networks, data analytics, interactive visualisation, human computer interaction, online citizen engagement, behaviour change, sports, exercise. The GetAMoveOn Network is a response to this research challenge.

Abstract

Innovative behaviour change interventions are needed to address the high sedentary behaviour and low physical activity levels in older adults. The increased use of modern technology by older adults presents an opportunity for such interventions to be delivered digitally. Just-in-time adaptive interventions (JITAIs) are a novel type of behaviour change interventions that capitalise on real time individual- and context-specific data that can be collected via mobile sensing technology that is inbuilt into mobile devices (e.g., smartphones). The data can be used to trigger adequate in-the-moment support. So far, the technology has been at the centre of attention in the development of such interventions, while other important elements (e.g. behavioral theory) have not featured prominently, which is likely related to the absence of dynamic models and theories of behaviour. The goal of this work is to integrate behaviour change and ageing theory and research as well as knowledge around older adult's technology use to develop a draft JITAI. The JITAI targets the distal outcome (ultimate goal) regular active breaks from prolonged sitting time. As a proximal outcome, the outcome that indicates short-term progress towards the distal outcome, we suggest daily activity breaks from prolonged sitting. The provision of prompts that encourage older adults to interrupt their sitting time should be based on a) accumulated sitting time, b) location of the individual, c) time of the day, d) frequency of daily support prompts, and e) response to previous support. Data on these variables can be collected using smartphones. Support prompts should be delivered via traditional text messages as older adults are familiar and comfortable with this function. The content of the prompts should encourage breaks from prolonged sitting time by highlighting immediate benefits. Ideas of light physical activities that could be done during the sitting breaks should also be provided. To further advance the field strategies to collect, aggregate, organise and immediately use temporally dense data are required. Machine learning and other

computational modelling techniques commonly used by computer scientists and engineers appear promising. To actualise these opportunities transdisciplinary teams and approaches are required. Resulting JITAIs can then be tested, and implemented by health providers.

Introduction

Populations are ageing at a rapid pace and this trend is projected to continue (Christensen et al., 2009; Rowe, 2015). For example, in 2050 about 21% of the world population will be 60 years or older; this is a strong increase from 2013 where the proportion of older adults compared to the overall global population was about 12% (United Nations, Department of Economic and Social Affairs, Population Division, 2013). An increase of the older adult population can also be observed in the United Kingdom where there are currently more people aged 65 or older than children under the age of 15 (Spijker and MacInnes, 2013).

One of the most effective ways to maintain health and wellbeing in older adulthood is to engage in regular physical activity (Sargent-Cox, Butterworth and Anstey, 2015; Ziegelmann and Knoll, 2015). Evidence for the relationship between physical activity and health in older adults comes from numerous studies. For example, physical activity is related to a long life in good health (Södergren, 2013). Others reported great effects of physical activity on cardiovascular health (Vogel et al., 2009) and immune system responses (Cherkas et al., 2008). Physical activity was also found to increase brain plasticity, improve cognitive functioning (Colcombe et al., 2006; Erickson, Gildengers and Butters, 2013; Olanrewaju et al., 2016) and positively impact on quality of life (Elavsky et al., 2005).

Unfortunately, physical activity levels among older adults are low (Sun, Norman and While, 2013). Studies conducted in the United Kingdom confirm this global trend. When physical activity was measured subjectively (via questionnaires or surveys) only between 11% and 23% of older adults were found to meet the minimal physical activity recommendations of

150 minutes moderate-to-vigorous physical activity (MVPA) per week (Allender, Foster and Boxer, 2008; Hillsdon et al., 2008; Stamatakis, Ekelund and Wareham, 2007). Others assessed physical activity objectively and found activity levels are well below the ones measured subjectively. Jefferis et al. (2014) measured physical activity with accelerometers and found that only about 13% of older adults are active enough and that activity levels decline with increasing age. The same study, among others, also showed that older adults are the most sedentary age group and that sedentary time increases with increasing age (Harvey, Chastin and Skelton, 2015; Matthews et al., 2008). The low physical activity and high sedentary behaviour levels among older adults warrant the development of innovative behavioural interventions.

In this paper we will consider digital sedentary behaviour and physical activity interventions in older adults while focussing mainly on Just-in-time adaptive interventions (JITAIs). These interventions bear promise to support people in sustainably changing their behaviour. They build on the opportunities of mobile sensing technology to capture real-life data which can then be used to trigger in-the-moment behavioural support. Unfortunately, most of these interventions are developed with the technology and its capabilities at the centre of attention. However, the people using the technology and theoretical as well as empirical considerations related to behaviour change have not featured prominently in the development process.

The primary aim of this paper is to develop a draft JITAI that is intended to impact sedentary behaviour (mainly sitting time) and light physical activity in older adults. For this, we will integrate theory and research findings related to behaviour change, ageing and technology use. We will specifically focus on the six intervention components of a JITAI: distal outcome, proximal outcomes, tailoring variables, intervention options, decision points, decision rules. Additionally, we will discuss potential limitations of JITAIs and introduce recent developments in the field that hold promise for future research and innovation.

Digital interventions targeting physical activity and sedentary behaviour in older adults

Digital-technology use in older adults

Older adults are increasingly technology-savvy and research shows that they are also interested in exploring new technologies (Gell et al., 2015; Heart and Kalderon, 2013; O'Brien et al., 2015; Zhou, Patrick Rau and Salvendy, 2014). This is especially true if technologies can be used to improve important aspects of life, such as health and wellbeing. Additionally, technologies need to be easy to use so that a) age-related limitations are no barriers, and b) barriers such as technology fear are reduced (Heart and Kalderon, 2013; Kurniawan, 2008; Parker et al., 2013; Vroman, Arthanat and Lysack, 2015). With this, there is a great potential to use digital technologies to promote health behaviours in older adults. This was underpinned by Reinwand and colleagues (2015) who showed that older adults are more likely to use digital lifestyle interventions as recommended compared to other age groups.

Physical activity and sedentary behaviour interventions in older adults using digital technology

Due to increased technology uptake by older adults, many researchers examined the potential of digital interventions to improve physical activity. A 2014 review on the effectiveness of non-face-to-face physical activity interventions in older adults showed that modern technology could be used to improve physical activity in this age group (Müller and Khoo, 2014). This was confirmed by a recent review that specifically looked into electronic health interventions (Muellmann et al., 2017). Generally, the research landscape has broadened in terms of the technologies that are being used and in terms of geographical spread. For example, interventions have been conducted using mobile phone text messages in the United States (Kim and Glanz, 2013) and Malaysia (Müller, Khoo and Morris, 2016). Others used the Internet (Belgium) (van Dyck et al., 2016), tablet computers (Italy) (Silveira et al., 2013), smartphone applications (United States) (King et al., 2013) and modern consumer-based activity trackers (United States) (Cadmus-Bertram et al., 2015; Thompson et al., 2014) to promote physical activity in older adults. The effects on physical activity behaviour change were mixed as some interventions were successful in increasing physical activity (Kim and Glanz, 2013; King et al., 2013; Müller, Khoo and Morris, 2016; van Dyck et al., 2016) and others were not (Cadmus-Bertram et al., 2015; Silveira et al., 2013; Thompson et al., 2014). In another study, Chase (2015) investigated the overall effectiveness of physical activity interventions in older adults. She identified 104 studies and found that interventions were generally effective. In addition, she reported significantly larger effects for digital physical activity interventions compared to interventions that were delivered in different ways (e.g., via group sessions). Only two studies targeted sedentary behaviour and showed moderate effects (King et al., 2013, 2016).

In spite of the inconclusive evidence, what is apparent is that modern technology can be used to deliver physical activity and sedentary behaviour interventions, and that more work is needed to design effective interventions that have a long-term effect on behaviour.

Underutilised potential of mobile technology

The mixed success of digital interventions highlight that the research community is yet to fully understand how to effectively utilise the opportunities that technology offers to provide effective behaviour change support. Particularly, the use of mobile technology such as mobile phones, smartphones and consumer-based wearable trackers is of interest as they are omnipresent in people’s lives (International Telecommunication Union, 2016). Using mobile technology to deliver health behaviour change interventions is promising as a large number of people can be reached for relatively low costs (Vandelanotte et al., 2016).

So far, mobile technology is mainly used as a delivery channel for interventions. In these interventions baseline characteristics such as age, education level and overall physical activity levels determine the time, type and frequency of behavioural support (tailoring). Once an intervention is build it is implemented and cannot be changed. For example, in a recent intervention older adults received one daily motivational text message at a pre-specified time (every weekday in the morning) over a fixed period of time (12 weeks). The message content was tailored to the study population (Müller, Khoo and Morris, 2016).

New and powerful mobile sensing technologies allow for the continuous collection of data on behaviour and its determinants (e.g., current location) during interventions. These data can be used to inform the choice of immediate support options in ongoing interventions (Hekler et al., 2016; Patrick et al., 2016; Riley et al., 2015; Spruijt-Metz et al., 2015). These interventions are called Just-in-time adaptive interventions (JITAIs) and the remainder of this paper is dedicated to this novel intervention design (Nahum-Shani, Hekler and Spruijt-Metz, 2015).

Just-in-time adaptive interventions (JITAIs)

Ecological Momentary Assessment – a precursor of JITAIs

The origins of JITAIs lie in Ecological Momentary Assessment (EMA) (Riley et al., 2015). In EMAs data of the behaviour in question and other relevant context information (e.g., emotional state, the environment, the purpose of behaviour, time of the day) are collected to gain a rich picture of various factors that can impact behaviour in real life. These data are measured using logs and questionnaires, and the information obtained can be used to inform the design of future interventions.

Due to the availability of mobile sensing technologies a great variety of behaviour and context data can now be collected in a non-intrusive manner (Hekler et al., 2013). Such data allow for a more detailed understanding of the unfolding of behaviour (Hekler et al., 2016). For example, smartphone accelerometers can collect data on activity patterns, and when a person reaches certain activity thresholds, a digital questionnaire can be triggered that asks the individual about the context (e.g. social environment, mood) of that activity. In addition, GPS data can be used to understand the relationship between certain activities and the geographic location. Capturing such real-time, individual and context data can identify ideal moments to deliver behaviour change support (Dunton, Dzubur and Intille, 2016); for example, knowing that a person is mostly sedentary when at work active breaks during working hours could be promoted.

JITAIs – a novel intervention design

Although traditional EMA studies provide valuable insights for tailoring and refining future interventions, they are only a means of collecting data. With new technologies that have considerable computing power data can be immediately aggregated and processed in order to adapt timing, content and intensity of behaviour change support in ongoing interventions

(Riley et al., 2015; Spruijt-Metz et al., 2015). This is crucial because support should ideally be delivered when an individual is either vulnerable to make a negative behavioural choice (e.g., using the lift instead of the stairs) or when there is an opportune moment to make a positive behavioural choice (e.g., going for a walk after sitting for a long time). As such moments can occur any time, it is important to recognise them and to trigger immediate support. For this support to have the desired impact the individual needs to be receptive. The receptivity depends largely on the type of support (e.g., message, audible signal) and the individuals' ability and/or motivation to process support and act upon it (Nahum-Shani et al., 2014; Nahum-Shani, Hekler and Spruijt-Metz, 2015). Hence, in-the-moment, individualised support that adapts dynamically to changing states and contexts is important.

JITAIs are an intervention design in which the type, time, intensity and content of behaviour support adapts based on real-time information of the individuals' internal state (e.g., mood, behavioural readiness), the behavioural context (e.g., location, time of the day) and previous responses to such support (e.g., an hour ago the individual walked after receiving a prompt) (Hekler et al., 2016; Nahum-Shani et al., 2016). As such, JITAIs capture and make use of the semi-random nature of real-life events and ever changing individual states and contexts that impact on what people do and how they behave. As a result, interventions are individualised throughout the whole intervention period based on obtained data (see Figure 1). Due to their dynamic nature, JITAIs can help individuals to sustainably change their behaviour in everyday life.

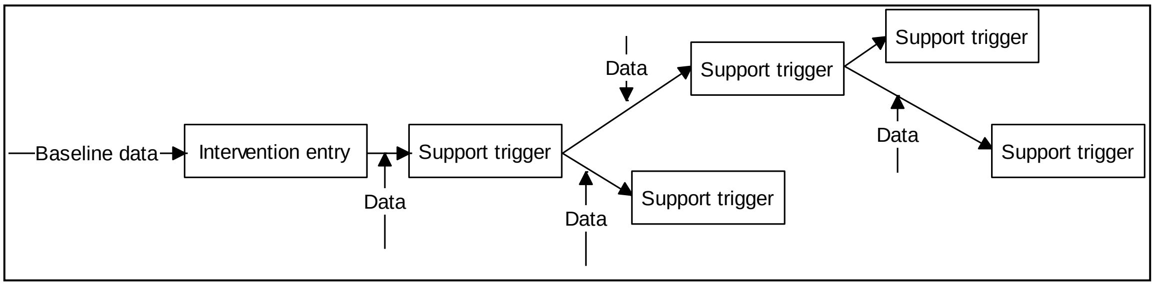

Figure 1: Simplified flow of a JITAI

Using portable mHealth technologies such as smartphones, wearable activity trackers and smart watches that are commonly equipped with sensors is particularly useful in JITAIs as they can collect relevant data and are usually in close proximity to the individual throughout the day (Hekler et al., 2013; Nahum-Shani, Hekler and Spruijt-Metz, 2015). For example, wearable trackers can collect behavioural (e.g., walking, sitting), physiological (e.g., heart rate) and geographical data that can then be used in conjunction with data from a digital questionnaire (e.g., on mood) to inform the selection of a specific supportive prompt.

The theory-technology gap

JITAIs are possible due to the ubiquitous nature of mobile devices that are equipped with sensing technology and that have considerable computing capabilities (McClernon and Roy Choudhury, 2013). These technologies can detect data on human activity, the environmental, social interactions, and physiological and psychological states (e.g., mood and well-being) (Riley et al., 2015; Spruijt-Metz et al., 2015). These data can then be used to trigger adequate behavioural support.

Mobile (sensing) technology is developing rapidly and ample opportunities to design strong individualised and context-specific real-time interventions arise frequently. However, current health behaviour theories are rather static as they focus on behavioural determinants that change slowly over time (e.g., age, attitudes). They provide a general, mostly simplified, framework of how certain factors influence behaviour (Hekler et al., 2016; Patrick et al., 2016). For example, the Theory of Planned Behaviour suggests that self-efficacy (confidence), subjective norms (what do others think about the behaviour) and attitudes influence behaviour (Ajzen, 1991). In contrast, JITAIs are also meant to address time-varying changes in individual states and contexts and their interaction (e.g., mood at current location) (Hekler et al., 2013; Hekler et al., 2016; Nahum-Shani et al., 2016).

Although there are no dynamic theories and models [1] attempts to integrate current behaviour change theories and empirical data when designing JITAIs are scarce (Nahum-Shani et al., 2016; Riley et al., 2015; Spruijt-Metz and Nilsen, 2014) as intervention developers mainly focus on the technology. The integration of relevant theoretical and empirical evidence pertaining to a specific target population and behaviour is a crucial first step for JITAI construction (Nahum-Shani, Hekler and Spruijt-Metz, 2015).

In the following sections we will describe the integration of behaviour change and ageing theory and empirical data with the goal of developing a draft JITAI targeting the replacement of sitting time with light physical activity in older adults. Where necessary, we will also consider technology adoption and use in older adults.

[1] The absence of dynamic behaviour theories and models relates to the fact that dense information about behavioural processes could not be collected previously and researchers relied mainly on data collected before and after an intervention. New technologies allow for the continuous collection of data Spruijt-Metz and Nilsen (2014).

JITAIs for active breaks from sitting time in older adults

JITAIs consist of six core components: distal outcome, proximal outcomes, tailoring variables, intervention options, decision points, and decision rules (Nahum-Shani et al., 2014). We will introduce and discuss these components as they relate to replacing sitting time with light physical activity in older adults. A framework outlining important questions to consider when addressing the six components will inform the integration of relevant theoretical and empirical evidence (Nahum-Shani, Hekler and Spruijt-Metz, 2015).

Component 1: Distal outcome

The distal outcome is the ultimate long-term goal of a JITAI. It needs to be meaningful in terms of tangible health benefits (Nahum-Shani, Hekler and Spruijt-Metz, 2015). Examples of distal outcomes include reduced sedentary behaviour and increased physical activity (van Dantzig, Geleijnse and van Halteren, 2013).

The World Health Organisation (2010) recommends that older adults should accumulate at least 150 minutes of moderate or 75 minutes of vigorous physical activity (a combination of both is possible). In addition, regular strengthening, flexibility and balancing activities are important. However, older adults are the least active and the most sedentary age group (Harvey, Chastin and Skelton, 2015; Jefferis et al., 2014; Matthews et al., 2008; Sun, Norman and While, 2013) and many have some physical limitations. Thus, promoting this amount of more intense activities seems unrealistic (Olanrewaju et al., 2016; Sparling et al., 2015). It also appears difficult to use a JITAI to promote more structured physical activities (e.g., strength exercises, exercise classes) because these need to be planned in advance and initiating them spontaneously is likely unfeasible.

An adequate distal outcome is the reduction of sedentary behaviour, especially sitting time, and the increase of light physical activities (e.g., walking or standing). This is because people who are sedentary also do little moderate or vigorous activity (Mansoubi et al., 2014), which means that sedentary older adults will likely accept targets around light physical activity better compared to more challenging ones (Greenwood-Hickman, Renz and Rosenberg, 2016). In addition, the Lifespan Theory of Control suggests that with increasing age very challenging activities might be difficult to accomplish. As a result, older adults are more committed if activities are in line with their current competencies and capacities (Heckhausen, Wrosch and Schulz, 2010).

Replacing sitting time with light physical activities is desirable from a public health point of view. Too much sitting increases the risk of premature death (van der Ploeg et al., 2012) and other health conditions (Garcia-Esquinas et al., 2017; Rezende et al., 2014). Increases in any activity are likely to buffer the negative effects of prolonged sitting (Ekelund et al., 2016; Sparling et al., 2015). Researchers also reported various benefits from active sitting breaks (Healy et al., 2008; Owen et al., 2010). Finally, sitting is habitual and thus breaks from sitting are opportunistic and can probably be promoted in the moment (with a JITAI) (Maher, Sliwinski and Conroy, 2017; Rutten et al., 2013).

With this, an appropriate distal outcome for older adults is to interrupt prolonged sitting with light physical activity on a regular basis.

Distal outcome: Regular interruptions of prolonged sitting with light physical activity

Component 2: Proximal outcome

Proximal outcomes are the mediators through which the distal outcome can be addressed (proximal outcomes impact distal outcome). With this, the proximal outcome is at the centre of a JITAI as it indicates progress towards the distal outcome. In order to identify meaningful proximal outcomes (or one meaningful proximal outcome) it is important to consult theory and research findings (Nahum-Shani, Hekler and Spruijt-Metz, 2015).

Many theories point to the importance of intentions to improve health behaviours (Ajzen, 1991). In addition, self-efficacy, the confidence to be able to perform a behaviour, can greatly impact physical activity adoption and maintenance in older adults (McAuley et al., 2003; van Stralen et al., 2009). Older adults who are more confident are more active. Other researchers found that social support or social interaction positively impacts physical activity (Anderson-Bill et al., 2011; Devereux-Fitzgerald et al., 2016; Smith et al., 2017). For example, Gellert et al. (2011) showed that older adults who joined a physical activity intervention with their life partners were more active compared to other participants. Although self-efficacy and social support are important, they are mainly relevant for more planned and structured physical activities. It is not reasonable to assume that self-efficacy or social support impact how often an (older) person takes breaks from prolonged sitting, as sitting is rather habitual. This was confirmed in a study with office workers who are potentially less in control of their sitting time (Hadgraft et al., 2017). The authors concluded that social-cognitive factors such as self-efficacy and social support do not drive changes in sitting time.

In the absence of conclusive evidence on crucial factors that directly impact activity breaks from sitting time (Bond et al., 2014; Gardner et al., 2016; Maher, Sliwinski and Conroy, 2017) it seems appropriate to focus on behavioural proximal outcomes. The most critical proximal outcome in our context is likely the short-term progress towards adopting and maintaining the behaviour (distal outcome) (Nahum-Shani et al., 2014). This is because in order to change a behaviour sustainably intermediate progress towards the behaviour is important.

An adequate proximal outcome that is important for the adoption of regular activity breaks from sitting is the number of breaks from prolonged sitting over a day. This means when an individual interrupts his/her sitting time throughout the day for a few weeks it is likely that breaks from sitting will soon become habitual. Figure 2 depicts this model.

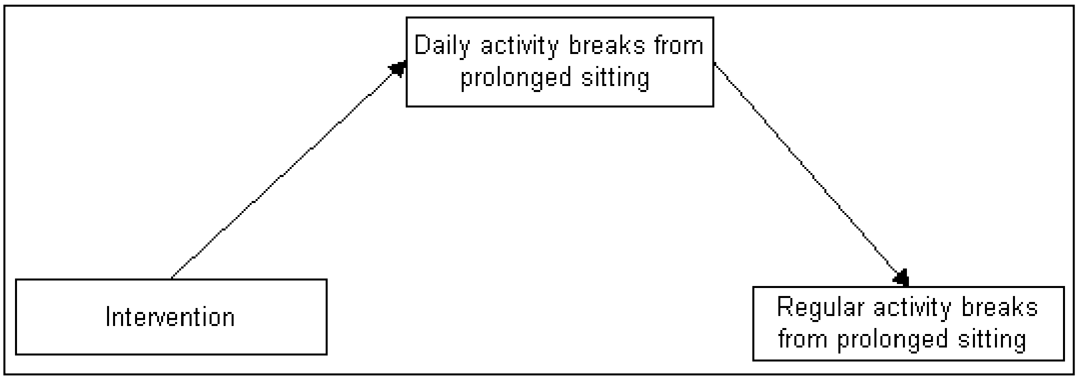

Figure 2: Intervention impact on distal outcome (regular activity breaks from prolonged sitting) via the proximal outcome (daily activity breaks from prolonged sitting)

Proximal outcome: Number of breaks during prolonged sitting over a day

Component 3: Tailoring variables

The tailoring variables indicate when, where and for whom specific behaviour change support should be delivered. The choice of tailoring variables is crucial because they identify circumstances that mark an opportunity to improve the behaviour in the moment and, with this, make progress towards the proximal outcome (Nahum-Shani et al., 2016). For example, the tailoring variable "current accumulated sitting time" might provide information on when it is best to support a person to have an active sitting break (potentially after prolonged sitting). Tailoring variables, other than behavioural ones, are also important because a number of individual and contextual factors can indicate an opportune moment for behavioural support (Nahum-Shani et al., 2014; Nahum-Shani, Hekler and Spruijt-Metz, 2015). These factors relate mainly to receptivity of support. For example, it is important to know if the person is able to break his/her sitting time when receiving support.

Consequently, the choice of tailoring variables need to be in line with theoretical and empirical evidence while also considering practical aspects (Nahum-Shani et al., 2016).

We propose five tailoring variables: accumulated sitting time, location of the individual, time of the day, frequency of support prompts per day, response to previous support. The first tailoring variable is probably the most obvious choice as it directly relates to sitting behaviour (see Figure 3). A similar tailoring variable was chosen by researchers who implemented a JITAI that aimed at reducing sitting time in office workers (van Dantzig, Geleijnse and van Halteren, 2013). There is some initial evidence from a JITAI study in obese adults on after how much sitting time people are likely to take active sitting breaks (Thomas and Bond, 2015). The authors found that participants who were prompted to interrupt their sitting time after 30 minutes accumulated most breaks and spent the longest time walking during these breaks when compared to participants who received prompts after longer sitting time.

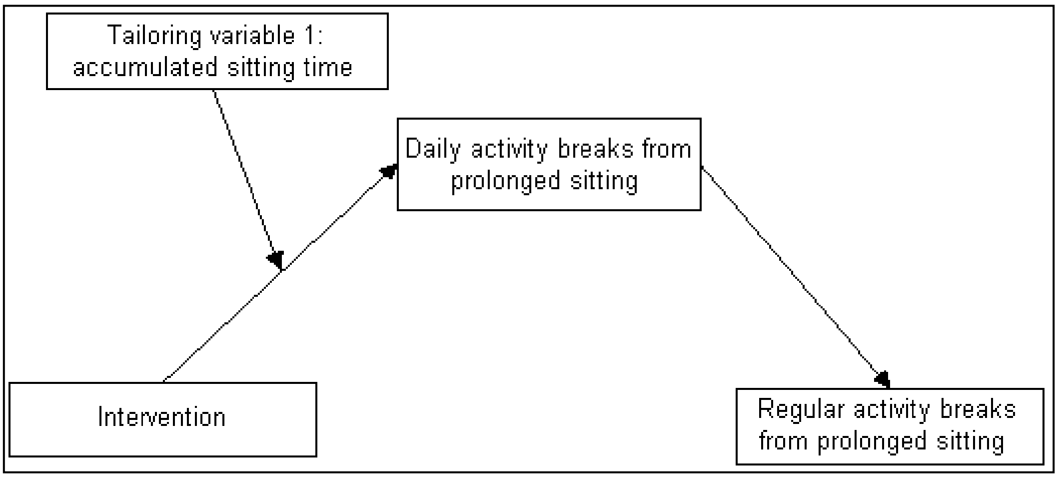

Figure 3: Relationship between the Tailoring Variable 1, the proximal and the distal outcome

The location of the individual is another important tailoring variable. Sitting time might not only be accumulated at home where the individual is likely to be able and willing to take active breaks. For example, when being at a public place such as the doctor’s waiting room or a café taking active breaks from sitting might not be possible or desirable. In such settings, people would not be very receptive of support. In addition, research also indicated that repeating a behaviour in a consistent setting (e.g., at home) is important during the initial stages of habit formation (Lally et al., 2010). This highlights that when the older adult is at home support might be most beneficial.

Another tailoring variable that is probably important is the time of the day. Research suggests that older adults accumulate most of their sitting time in the evening hours (Fitzsimons et al., 2013; Gardiner et al., 2011; Gennuso et al., 2016). A study carried out with older adults showed that participants were more in favour of taking active sitting breaks in the evening compared to other parts of the day (Gardiner et al., 2011). This might be because they have some chores to complete throughout the day (e.g., going shopping, taking care of grandchildren) and have more opportunities to sit for longer later in the day. Hence, receptivity of support prompts might be higher in the evening.

The next tailoring variable is the response to support prompts sent earlier. If the older adult had an active break after a prompt, providing support prompts at a later time might not be appropriate because the person might not be open to too many sitting time interruptions. Older adults are usually very sedentary (they accumulate between 8 and 11h of sedentary time per day) (Harvey, Chastin and Skelton, 2015; Matthews et al., 2008) and the sedentary behaviour has become a habit over a long time (e.g., sitting in front of the TV after dinner). Alterations to these long-term behavioural patterns are difficult to achieve (Greenwood-Hickman, Renz and Rosenberg, 2016). Reducing sitting time in a step-by-step manner is likely most acceptable (Gardner, Lally and Wardle, 2012) and avoids burden (Nahum-Shani et al., 2014). Evidence for this comes from Rosenberg and colleagues (2015). They found that none of their older research participants achieved 15 or more sitting time breaks per day and concluded that more realistic targets should be in place. If the older adult does not respond to a few support prompts it might not be desirable to continue providing such prompts even if they are due (based on sitting time data). The person might simply not be in the mood to interrupt his/her sitting time and the receipt of a prompt could be disturbing.

It is also important to limit the frequency of support prompts to minimise burden. In a JITAI study that addressed sitting time in office workers, the researchers limited the number of daily support prompts to three (van Dantzig, Geleijnse and van Halteren, 2013). Research participants responded positively to this. However, Thomas and Bond (2015) found more frequent prompts (seven per day) lead to more sitting time interruptions in obese adults. More research, especially in older adults, is required.

In addition to identifying appropriate tailoring variables it is important to decide how these should be measured. The measurement method can impact the a) accuracy of the identification of an opportune moment, b) burden felt by participants, and c) cost and flexibility of assessments (Nahum-Shani et al., 2014; Nahum-Shani et al., 2016).

It first needs to be decided whether tailoring variables should be measured passively (automatically via sensors) and/or actively (e.g. via digital questionnaires) (Nahum-Shani et al., 2014; Nahum-Shani et al., 2016). For the tailoring variables we propose in this paper passive measurements appear most appropriate because all variables can be measured with a smartphone (King et al., 2013, 2016). Passive measurement will also reduce burden as no information input is required (Nahum-Shani et al., 2014). This is especially important for older adults who might be cognitively challenged to provide an adequate account of the momentary context (Levy, 1999). In addition, passive measurement increases the validity and reliability of the collected data.

The final question concerns the technology that should be used for measuring the tailoring variables. Although older adults are increasingly interested in using mobile technology (Gell et al., 2015; Vroman, Arthanat and Lysack, 2015) their uptake of newer devices such as smartphones is still low (PEW Research Centre, 2017; Statistica, 2016). Furthermore, when older adults use such technologies they tend to use only a few functions (Heart and Kalderon, 2013). This might be because they experience problems navigating around complex menus (Zhou, Patrick Rau and Salvendy, 2014). It is expected that the use of more complex technologies, especially smartphones, will increase in the coming years and that older adults become skilled users (Ofcom, 2015). Even if they still have limited skills this is not a major barrier to sensor-based, automatic data collection. Thus, all tailoring variables can be measured with a smartphone, but the use of additional wearable activity trackers would be beneficial.

Sitting time and responses to previous support can be measured with the smartphone-inbuilt accelerometer/inclinometer. However, older adults might not want to carry the device on the body when at home. Using wearable activity trackers might be an alternative. Small physical activity studies showed that older adults accepted such trackers well (Cadmus-Bertram et al., 2015; Lyons et al., 2017). Others also reported that older adults found these devices easy to use and useful (McMahon et al., 2016). Arguably, this might be because older adults received extensive training. On the contrary, researchers suggested that older adults are reluctant to use more than one device at the same time (King et al., 2013, 2016). It is also important to consider that uptake and long-term use of trackers remain questionable (O'Brien et al., 2015). The location can be measured with the in-built GPS and time of the day with the in-built clock.

Tailoring variable 1: Accumulated sitting time measured with smartphone accelerometer/inclinometer, and/or wearable activity tracker.
Tailoring variable 2: Location of the individual measured with smartphone GPS.
Tailoring variable 3: Time of the day measured with smartphone clock.
Tailoring variable 4: Frequency of support prompts per day.
Tailoring variable 5: Response to previous support prompts.

Component 4: Intervention options

The intervention options are the support prompts that are triggered when the tailoring variable data indicate an opportune moment (Nahum-Shani, Hekler and Spruijt-Metz, 2015). There are an unlimited number of possible intervention options. However, intervention options should be selected in light of a) theoretical and empirical evidence which point to the options that are most likely to positively impact the behaviour, b) the possibility to deliver the support in a just-in-time manner (Nahum-Shani, Hekler and Spruijt-Metz, 2015), and c) appropriateness and feasibility (e.g., consider appropriateness of going for a walk at 9pm).

Research on promoting active breaks from sedentary behaviour in older adults is limited. A recent review found that self-monitoring and problem solving are very promising for the promotion of active sitting breaks (Gardner et al., 2016). In contrast, other researchers found such behaviour change techniques not to be effective in older adults because they are too cognitively demanding, undermine autonomy and are irrelevant (French et al., 2014; Warner et al., 2016).

According to the Socioemotional Selectivity Theory older adults are mainly interested in present-oriented and personally relevant incentives of behaviour because of the prominent perception that their lifespan is limited (Carstensen, Isaacowitz and Charles, 1999; Charles and Carstensen, 2010). This was confirmed in two recent studies (Devereux-Fitzgerald et al., 2016; Greenwood-Hickman, Renz and Rosenberg, 2016). The researchers reported that joy and immediate health benefits were important motivators for improving physical activity and reducing sedentary behaviour. Thus, making older adults aware of these immediate benefits of active sitting breaks is important. In addition, it is useful to provide activity ideas for these breaks. Practical activities such as getting up to make a cup of tea are probably acceptable (Greenwood-Hickman, Renz and Rosenberg, 2016). A brief prompt to encourage older adults to stand up for a short time after prolonged sitting can be Intervention Option 1.

Intervention Option 2 should consist of positive feedback if sitting time was interrupted following the previous prompt (e.g., '*You have managed to move for 3 minutes since the last prompt. Well done! You are well on your way to reduce your sitting time.'*) and encouragement to repeat this behaviour. The Provide Nothing Option (Intervention Option 3) is important in case an immediate interruption of sitting time is not possible (e.g., person is in a café) or in case the individual is not receptive of support (e.g., sitting time was interrupted successfully a few times during the day).

Finally, it is important to consider the delivery of the intervention options because this can affect their impact. As highlighted earlier, older adults have lower smartphone uptake compared to other age groups, and older adults use only a limited number of the available mobile device functions (Heart and Kalderon, 2013; Statistica, 2016). They feel most comfortable with traditional, less complex mobile phone functions, especially text messaging (Gell et al., 2015). As a result, it appears most appropriate to deliver Intervention Options 1 and 2 through text messages. This is likely to reduce cognitive burden while, at the same time, increasing ease of use. Ideally, an audible signal alerts the individual to the arrival of a text message. This ensures the availability of some support (reminder) even if the individual does not intend to read the message.

Intervention Option 1 (delivered via text message): Provide prompt to encourage standing up to do some light movements for a brief period. Highlight immediate benefit of doing this and provide activity ideas.

Intervention Option 2 (delivered via text message): Provide feedback on previous (positive) response to support prompt. In addition, encouragement to stand up and move for brief period.

Intervention Option 3: Provide nothing.

Component 5: Decision points

The decision point is the point in time at which an intervention option (support) is triggered (Nahum-Shani et al., 2014; Nahum-Shani, Hekler and Spruijt-Metz, 2015). Decision points are flexible and their frequency mainly depends on opportunities that arise to positively impact behaviour (level of the tailoring variables). With this, the decision points are the in-the-moment component of a JITAI because they are guided by the dynamic of the tailoring variables.

To support older adults to replace some of their sitting time with light physical activities the evening hours present the best window of opportunity (Gardiner et al., 2011; Gardiner et al., 2011). Here we propose a time interval for decisions points from 5pm to 9pm. At what specific time which intervention option is triggered will depend on the level of Tailoring Variables 1, 2, 4 and 5. For example, if at any time between 5pm and 9pm there is a period of uninterrupted sitting time (e.g., 30 minutes), and the older adult is at home, he/she responded positively to a previous support prompt, and less than three support prompts were provided on that day a decision about the appropriate intervention option is made.

Time interval for decision points: From 5pm until 9pm.

Component 6: Decision rules

The decision rules systematically link the components of a JITAI. Good decision rules specify intervention options that have the most beneficial impact on the proximal outcome based on the levels of the tailoring variables at any decision point (Nahum-Shani et al., 2014; Nahum-Shani, Hekler and Spruijt-Metz, 2015). JITAIs include many decision rules because of the various levels and interactions of the tailoring variables and the different intervention options. Here we constructed seven decision rules (see Figure 4). For example, if the older adult accumulates less than 30 minutes of uninterrupted sitting time

Intervention Option 3 will be triggered (no intervention, Decision Rule 1). If an older adult accumulates at least 30 minutes of uninterrupted sitting time and he/she is at home, it is between 5pm and 9pm, and no support prompt has been delivered before on that day Intervention 1 will be triggered (support prompt, Decision Rule 4). A summary of all JITAI components is provided in Appendix 1.

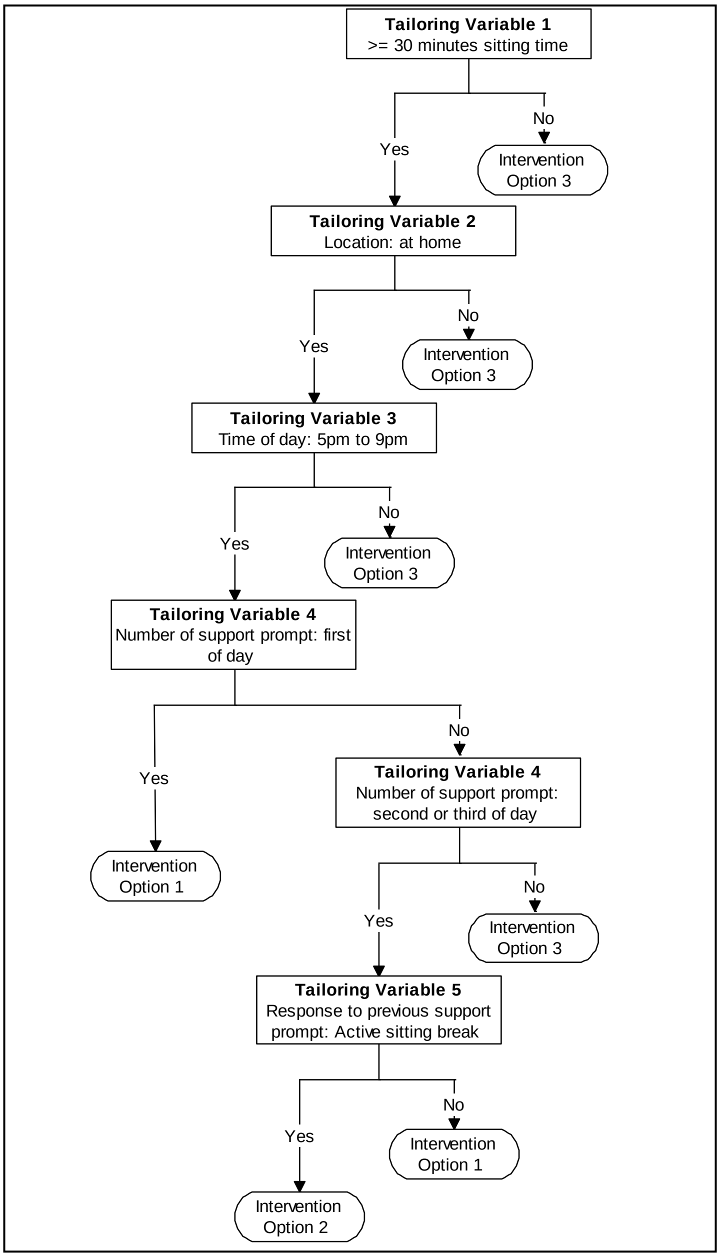

Figure 4: Draft JITAI to reduce sitting time in older adults.

Decision rule 1: If current accumulated sitting time < 30 minutes Then, Intervention Option 3.

Decision rule 2: If current accumulated sitting time ≥ 30 minutes, and {location at home = No} Then, Intervention Option 3.

Decision rule 3: If current accumulated sitting time ≥ 30 minutes, and {location at home = Yes, time of the day 5pm to 9pm = No} Then, Intervention Option 3.

Decision rule 4: If current accumulated sitting time ≥ 30 minutes, and {location at home = Yes, time of the day 5pm to 9pm = Yes, first support prompt of day = Yes} Then, Intervention Option 1.

Decision rule 5: If current accumulated sitting time ≥ 30 minutes, and {location at home = Yes, time of the day 5pm to 9pm = Yes, first support prompt of day = No, second or third support prompt of day = No} Then, Intervention Option 3.

Decision rule 6: If current accumulated sitting time ≥ 30 minutes, and {location at home = Yes, time of the day 5pm to 9pm = Yes, first support prompt of day = No, second or third support prompt of day = Yes, active sitting break following previous prompt = No} Then, Intervention Option 1.

Decision rule 7: If current accumulated sitting time ≥ 30 minutes, and {location at home = Yes, time of the day 5pm to 9pm = Yes, first support prompt of day = No, second or third support prompt of day = Yes, active sitting break following previous prompt = Yes} Then, Intervention Option 2.

Discussion

Due to the limited availability and/or effectiveness of physical activity and sedentary behaviour policies (Olanrewaju et al., 2016; Reis et al., 2016) there is a need for self-managed health behaviour adoption and maintenance. JITAIs are a novel intervention design that capitalises on mobile sensing technology to collect real-time individual and context data which is used to provide in-the-moment support (Nahum-Shani et al., 2014; Nahum-Shani et al., 2016; Nahum-Shani, Hekler and Spruijt-Metz, 2015). These interventions were successful in increasing physical activity and/or reducing sedentary behaviour in a few small studies involving adults (Consolvo et al., 2008; van Dantzig, Geleijnse and van Halteren, 2013) and older adults (Bond et al., 2014; King et al., 2013, 2016) (see Appendix 2 for a summary of these studies). The changes in sedentary behaviour were moderate and largely comparable to the changes achieved in other interventions that did not provide just-in-time adaptive support (Barone Gibbs et al., 2016; Fitzsimons et al., 2013; Gardiner et al., 2011; Maher, Sliwinski and Conroy, 2017; Rosenberg et al., 2015).

In this paper we developed a draft JITAI that can be used to help older adults to reduce their sitting time by replacing some of it with light physical activity. We integrated behaviour change as well as ageing theory and evidence, and also considered older adults' technology adoption and use. We hope our work provides intervention developers a starting point for the design of future JITAIs.

Although we carefully integrated theories and research findings to arrive at the draft JITAI it is important to highlight that not all tailoring variables that could indicate opportunities for support to impact sitting time were considered. In this paper we focussed on tailoring variables that can be assessed in a passive and unobtrusive manner using smartphones and their inbuilt sensors. This choice was made because passive measurement minimises burden and allows for flexible as well as accurate assessments (Nahum-Shani et al., 2016). We acknowledge that other tailoring variables than those included in our JITAI are likely also important. For example, the internal state (happy, annoyed or energised) might be a promising tailoring variable to identify moments in which behaviour support can be beneficial, but also detrimental (Nahum-Shani et al., 2016). If an older adult had some negative experiences he/she might be annoyed. In such situations providing support to take an active break from sitting could be perceived negatively even though all other tailoring variables point to an opportune moment for such support. However, assessing mood might not be desirable because it required the input of information into a mobile device. This will increase burden and might lead to disengagement with the intervention (Nahum-Shani, Hekler and Spruijt-Metz, 2015). With this, only a limited number of tailoring variables from the unlimited set of variables can and/or should be assessed. Additionally, the complex and time-varying interactions between psychological, contextual and behavioural tailoring variables which impact behaviour were not captured in our work. This is mainly because these interactions and their implications are difficult to anticipate (Nahum-Shani, Hekler and Spruijt-Metz, 2015; Spruijt-Metz et al., 2015).

In addition to the adaptations based on an individuals' psychological state and the context, JITAIs should also adapt to the progress towards the proximal and distal outcome (Nahum-Shani et al., 2016). For example, when an older adult successfully interrupted his/her sitting time in the evening for a few weeks the frequency of support prompts could be increased to ensure further sitting time reductions. That means that the decision rules proposed in this paper will need to change over time (Nahum-Shani et al., 2016). When such adaptations to decisions rules should be made is not clear. The limited evidence suggests that the adoption of a healthy habit can take between 18 and 254 days (median: 66 days) (Lally et al., 2010). This study provides little guidance on when decision rules should be adapted in a

JITAI targeting sedentary behaviour in older adults because a) the researchers included younger adults who were motivated to change their behaviours and b) the reduction of sedentary behaviour was not assessed. Older adults might need longer time to adopt a new behaviour due to long-established habits. On the contrary, taking active sitting breaks is not as complex as increasing physical activity. Thus, habit formation might not take very long. The fact that the JITAI studies published to date described minimal (King et al., 2013, 2016) or even no adaptations (Bond et al., 2014; Consolvo et al., 2008; van Dantzig, Geleijnse and van Halteren, 2013) to decision rules highlights that not all opportunities that JITAIs offer are currently utilised.

As JITAIs capitalise on mobile technology questions around feasibility and cost-effectiveness to implement large-scale interventions in older adults need to be answered. Although the 'digital divide' is narrowing older adults show lower technology adoption and use compared to other age groups (Gell et al., 2015; McMahon et al., 2016). This is especially true for very recent technologies which bear most promise for JITAIs. It is hence necessary to train older adults in using these technologies (Parker et al., 2013). In the three JITAI studies that targeted physical activity and sedentary behaviour in older adults training sessions prior to the interventions were conducted to familiarise the participants with the technologies (Bond et al., 2014; King et al., 2013, 2016). For example, King and colleagues (2013, 2016) provided a 1-hour one-to-one training session for each participant. A helpline was also established to troubleshoot problems. Even more support might be necessary for the older old who experience most barriers to technology use (McMahon et al., 2016). Providing such support on a larger scale might be impractical and cost-ineffective. Yet, if older adults successfully adopt modern mobile technologies JITAIs might have a long-term impact on behaviour. This is because older adults are less likely to abandon these technologies (McMahon et al., 2016) and are more adherent to digital interventions compared to younger age groups (Reinwand et al., 2015). There is another benefit of a face-to-face introductory session prior to a JITAI. Older adults can be made aware of their sedentary behaviour and intentions to reduce time spent sedentary can be formed (Maher, Sliwinski and Conroy, 2017). The JITAI can then function as a bridge between intentions and behaviour. This will likely increase the sustainability of behaviour change.

Future work

JITAI research is in its early infancy (Nahum-Shani et al., 2016) and the draft JITAI developed here is a necessary step for the advancement of such interventions. Our JITAI is limited as it does not account for a) all potentially important individual and contextual factors that can impact sitting time, b) time-varying changes of these factors, and c) complex and changing interactions between these factors.

Understanding these complexities and theorising them solely from a behavioural science point of view is neither feasible nor fruitful as they are variable from individual to individual. To further refine the JITAI and to ensure effective behaviour change we need temporally dense longitudinal data from various sources that can be fed back into the JITAI to allow for continuous adaptations at the individual level (feedback loop) (Spruijt-Metz et al., 2015). Strategies of data aggregation, connection and organisation for continuous model refinement are common in computer science and engineering and are often referred to computational modelling (such as machine learning or system identification) (Hekler et al., 2016; Spruijt-Metz et al., 2015). With advancing sensor technologies that are increasingly integrated in smartphones and other mobile devices, and the use of machine learning approaches it is possible to understand and impact individual behaviour in real-time (Spruijt-Metz et al., 2015). This is likely to significantly change behavioural health research and practice as it will allow us to generate behavioural theories and models that are informed by classical theories (that are concerned with more stable factors), refined by data (of dynamic factors), and individually adaptable. However, such work requires transdisciplinary teams involving behavioural health experts, engineers and computer specialists (Hekler et al., 2016; Nahum-Shani et al., 2016; Spruijt-Metz and Nilsen, 2014). Finally, it is essential to consider the ethical implications related to the collection dense personal data necessary for adaptive interventions.

Conclusions

Health behaviour intervention research and practice has come a long way. From the early days where interventions were generic and intended to help all people in all contexts, to interventions that were tailored based on baseline data we are now approaching the era of behaviour change interventions, such as JITAIs, that are continuously adapted based on data collected through modern technology (Patrick et al., 2016).

The primary merit of JITAIs is that they recognise and make use of the momentary context of behaviour that can have a profound impact on the adoption and maintenance of health behaviours. Modern technology enables us to collect chunks of information of this context; and this information can then be used to trigger immediate support. In this paper we integrated behavioural health and ageing theory and research as well as knowledge around the use of technology by older adults to arrive at a draft JITAI targeting the interruption of sitting time with active breaks. Our draft JITAI can be tested and further refined to make it fit for purpose in health promotion settings. Further advancement will be made if temporally dense contextual data is collected and fed back into the JITAI (via machine learning). This will only be possible if transdisciplinary teams consisting of behavioural scientists, engineers and computer specialists work together.

Finally, despite the great opportunities technology provides, it is crucial to realise that participants require an adequate level technology acceptability and expertise. This can be a barrier when implementing JITAIs in older adults, and resource-intense measures might need to be taken to familiarise older adults with the respective technologies.

Summary of impact

In this paper we designed a draft JITAI that can be tested and further refined so that it can be used by health promoters. In addition to this tangible output we also hope to stimulate debate about:

a) The possibilities and challenges of using modern sensing technology to address physical activity and sedentary behaviour in older adults.

b) The complexities of people's health behaviours and how individual, contextual and other factors interact.

c) The importance of transdisciplinary teams consisting of behavioural health experts, engineers and computer scientists to understand and sustainably impact sedentary behaviour and physical activity of (older) people using modern technology.

Our work also has implications for contemporary health promotion interventions. Such interventions should encourage reductions in sedentary behaviour in a step-by-step manner. Short encouraging prompts could be sent to older adults in the evening hours to animate them to take active sitting breaks. Such support could be delivered via simple technologies such as text messages.

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Appendix

Appendix 1: Draft JITAI

Distal outcome	Proximal outcome	Tailoring variables	Intervention options	Decision points	Decision rules
Regular interruptions of prolonged sitting with light physical activity	Number of breaks during prolonged sitting over a day	*Tailoring variable 1:* Accumulated sitting time measured with smartphone accelerometer/inclinometer, and/or wearable activity tracker. *Tailoring variable 2:* Location of the individual measured with smartphone GPS. *Tailoring variable 3:* Time of the day measured with smartphone clock. *Tailoring variable 4:* Frequency of support prompts per day. *Tailoring variable 5:* Response to previous support prompts.	*Intervention Option 1 (delivered via text message):* Provide prompt to encourage standing up to do some light movements for a brief period. Highlight immediate benefit of doing this and provide activity ideas. *Intervention Option 2 (delivered via text message):* Provide feedback on previous (positive) response to support prompt. In addition, encouragement to stand up and move for brief period. *Intervention Option 3:* Provide nothing.	*Time interval for decision points:* From 5pm until 9pm.	*Decision rule 1:* If current accumulated sitting time < 30 minutes Then, Intervention Option 3. *Decision rule 2:* If current accumulated sitting time ≥ 30 minutes, and {location at home = No} Then, Intervention Option 3. *Decision rule 3:* If current accumulated sitting time ≥ 30 minutes, and {location at home = Yes, time of the day 5pm to 9pm = No} Then, Intervention Option 3. *Decision rule 4:* If current accumulated sitting time ≥ 30 minutes, and {location at home = Yes, time of the day 5pm to 9pm = Yes, first support prompt of day = Yes} Then, Intervention Option 1. *Decision rule 5:* If current accumulated sitting time ≥ 30 minutes, and {location at home = Yes, time of the day 5pm to 9pm = Yes, first support prompt of day = No, second or third support prompt

Distal outcome	Proximal outcome	Tailoring variables	Intervention options	Decision points	Decision rules
					of day = No} Then, Intervention Option 3. *Decision rule 6:* If current accumulated sitting time ≥ 30 minutes, and {location at home = Yes, time of the day 5pm to 9pm = Yes, first support prompt of day = No, second or third support prompt of day = Yes, active sitting break following previous prompt = No} Then, Intervention Option 1. *Decision rule 7:* If current accumulated sitting time ≥ 30 minutes, and {location at home = Yes, time of the day 5pm to 9pm = Yes, first support prompt of day = No, second or third support prompt of day = Yes, active sitting break following previous prompt = Yes} Then, Intervention Option 2.

Appendix 2: Rapid systematic review on JITAIs targeting physical activity or sedentary behaviour in older adults

We conducted a systematic search in Web of Science to identity JITAI studies that targeted physical activity or sedentary behaviour in older adults. The search was limited to papers written in English published between 2008 and 21st March 2017. Due to the novelty of JITAIs we do not expect that there are studies prior to 2008. Also Nahum-Shani and colleagues (2014) suggested that the earliest JITAI study targeting physical activity was published in 2008 (Consolvo et al., 2008). We conducted title, abstract and keyword searches using the following terms (with the appropriate truncations):

- Group a) JITAI, just-in-time adaptive intervention, intensively adaptive intervention, adaptive intervention, in the moment
- Group b) physical activity, motor activity, outdoor activity, exercise, physical exercise, walk, sport, active transport, sit, sedentary, active commuting
- Group c) older adult, elderly, senior, retiree, pensioner, older people, older person, aged

To identify additional studies, we hand searched reference lists of relevant publications and conducted forward and backward citation tracking.

Our search identified 20 potentially relevant titles of which 19 were not included because they did not describe a JITAI for PA and/or sedentary behaviour. One study reported on a JITAI for physical activity promotion in adults. However, as older adults were part of the JITAI and the mean age of study participants was 48 years we decided to include this study (Bond et al., 2014). In addition, our hand search resulted in two other study that were included in the review (King et al., 2013, 2016).

Bond and colleagues (2014) targeted the interruption of sitting time with light physical activity in 30 overweight and obese adults. They used a smartphone accelerometer to measure sedentary time. The collected data was for the research participants to monitor their sedentary time with an application. Audible prompts encouraging active breaks of 3, 6 and 12 minutes were delivered when prolonged sitting of 30, 60 or 120 minutes was detected. Positive reinforcement was provided if participants interrupted their sitting time. Sitting time reduced (6%) and physical activity increased significantly following the JITAI. Encouraging shorter breaks (3 minutes) after shorter periods of prolonged sitting (30 minutes) was most effective.

King and colleagues (2013) developed three smartphone applications to increase physical activity and reduce sedentary behaviour in 68 older adults (mean age 59 years). They used the inbuilt accelerometer to collect physical activity and sedentary behaviour data. This data was used to provide just in-time feedback which participants could actively access (in contrast to passive receipt of support). The applications differed in the way they delivered behaviour change support: analytical app, social app, affective app. At the end of the 8-week intervention within-group analysis revealed that physical activity increased and sedentary time decreased significantly (irrespective of the app that was used). Participants were also highly satisfied with the intervention and reported that they would also use the apps for longer. This was confirmed in their latest study where the social app had the greatest impact on physical activity and sedentary behaviour (King et al., 2016).

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Trained as a sport scientist in Germany, my research primarily focuses on e- & mHealth physical activity interventions. During my PhD I developed, implemented and evaluated an mHealth exercise intervention targeting older adults in multi-ethnic Malaysia. With this, I have a strong background and interest in behavioural health research in diverse populations (older adults and culturally diverse people). Due to my excellent collaborative ties with colleagues from various regions I am fortunate to be able to support the development of respective research initiatives. Currently, I am a research fellow in Health Psychology at the University of Southampton. Here, I am leading the physical activity component of various multi-component digital health interventions. As a committee member of the e- & mHealth Special Interest Group affiliated to the International Society of Behavioural Nutrition and Physical Activity (ISBNPA) I also contribute meaningfully to various efforts to progress the field.

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