USING THE BEHAVIOUR CHANGE WHEEL TO DEVELOP AN INTERVENTION TO REDUCE SEDENTARY BEHAVIOUR IN UNIVERSITY STUDENTS

A Thesis submitted by

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Abstract

Background: High levels of sedentary behaviour – waking activities that involve sitting or reclining and a low amount of energy expenditure – are associated with negative health outcomes. University students are a population subgroup that is at risk of engaging in excessive sedentary behaviour, as a significant proportion of their time is spent studying or in class. The main aim of this PhD project was to lay the groundwork for and develop an intervention aimed at reducing and breaking up sedentary behaviour in university students using the Behaviour Change Wheel, a theory-driven intervention development framework (phase one). A second aim was to conduct a pilot trial on the feasibility and preliminary short-term results of the sedentary behaviour change intervention (phase two).

Methods: The intervention development phase included systematic literature reviews and one-on-one interviews with university students (n = 18) to understand what needs to change for the target behaviour to occur, according to the Capability, Opportunity, Motivation, Behaviour model and the complementary Theoretical Domains Framework. Phase two consisted of piloting the behaviour change intervention using a quasi-experimental study design (n = 9). The intervention content was delivered through a face-to-face session, together with daily text messages reinforcing the key intervention messages (sit less – move more, more often). Outcomes were assessed at two different time points (pre/post) and included accelerometer-based (activPAL) and self-reported (Nightly-Week-U) total sedentary time, as well as accelerometer-assessed number of steps and prolonged sedentary time. In addition to the outcome evaluation, a mixed-methods process evaluation informed by the UK Medical Research Council's framework was included as part of the trial to assess the acceptability of implementation structures, clarify causal mechanisms, and identify relevant contextual factors.

Results: Findings from phase one, together with previous literature, helped identify the factors that need to change for the students to reduce and break up their sedentary time (e.g., increase knowledge on the health effects of sedentary behaviour, notice and remember to break up sedentary behaviour). By using the Behaviour Change Wheel, it was possible to generate possible intervention strategies directly from this behavioural diagnosis (e.g., provide education, schedule regular prompts to break up

sedentary time) and select the most appropriate mode of delivery. Findings from phase two indicated the intervention protocol and its assessment is feasible and acceptable. Moreover, results suggested the intervention might assist university students in reducing sedentary behaviour and increasing movement, albeit the short-term effects were limited to weekend days. Based on the process evaluation findings, different add-on strategies were recommended to further develop the intervention and increase its effectiveness (e.g., establish a collaboration with university staff or introduce sit-to-stand desks).

Conclusions: This thesis featured an evidence-based, theory-informed approach to developing and evaluating an intervention to reduce sedentary behaviour. Findings may be used as a guide for future intervention developers. The different studies included in the PhD have contributed to the literature by providing a greater understanding of sedentary behaviour in university students, including novel insights on how to better reduce sedentary time and enhance movement specifically for this population subgroup.

Certification of Thesis

This Thesis is the work of Oscar Castro except where otherwise acknowledged, with the majority of the authorship of the papers presented as a Thesis by Publication undertaken by the Student. The work is original and has not previously been submitted for any other award, except where acknowledged.

Principal Supervisor: Professor Stuart Biddle

Associate Supervisor: Dr. Jason Bennie

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Student and supervisors signatures of endorsement are held at the University.

Statement of Contribution

The following detail is the agreed share of contribution for candidate and co-authors in the presented publications in this thesis. All journal impact factors (IF) and source-normalised impact per paper (SNIP) are based on the Thomson Reuters 2020 Journal Citation Reports (Web of Science) and the CWTS Journal Indicators, respectively. Citations are extracted from Google Scholar (January 2021):

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The overall contribution of ***Oscar Castro*** was 80% to the concept development, analysis, drafting and revising the final submission; ***Jason Bennie***, ***Ineke Vergeer***, ***Grégoire Bosselut***, and ***Stuart J. H. Biddle*** contributed the other 20% to concept development, analysis, editing and providing important technical inputs.

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- **Article IV**: Oscar Castro, Ineke Vergeer, Jason Bennie, and Stuart J. H. Biddle. Feasibility of reducing and breaking up university students' sedentary behaviour: Pilot trial and process evaluation. Pre-print version.

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List of Conference Presentations

Oscar Castro, Jason Bennie, Ineke Vergeer, Grégoire Bosselut, and Stuart J. H. Biddle (2018, March). *Correlates of sedentary behaviour in university students: A systematic review*. Poster presented at the Exercise and Sport Science Australia 'Research to Practice' Conference, Brisbane, Australia.

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Abbreviations

BCTs	Behaviour Change Techniques
BCW	Behaviour Change Wheel
CMA	Comprehensive Meta-analysis
COM-B	Capability-Opportunity-Motivation Behaviour model
CORE-Q	Consolidated Criteria for Reporting Qualitative Research
IPAQ	International Physical Activity Questionnaire
MOOSE	Meta-analysis of Observational Studies in Epidemiology
MRC	UK Medical Research Council
NHANES	US National Health and Nutrition Examination Survey
NWU	Nightly-Week-U Questionnaire
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-analyses
TDF	Theoretical Domains Framework
USQ	University of Southern Queensland

Chapter 1 Introduction and Rationale

1.1 Overview of the Chapter

The purpose of this chapter is to review the relevant scientific literature concerning the PhD topic and define the key concepts and rationale for the project. First, the concept of sedentary behaviour is introduced, reviewing the evidence on its health effects as well as its associations with physical activity. Second, previous studies targeting sedentary behaviour change in university students are discussed, with a focus on the importance of conducting theory-informed interventions. Third, the Behaviour Change Wheel (BCW) framework is presented, including the Capability-Opportunity-Motivation Behaviour model (COM-B) and the Theoretical Domains Framework (TDF). Last, the PhD aims are defined with regards to the state of the evidence, as outlined in the introduction.

1.2 What is Sedentary Behaviour?

Over the past decades, behaviours such as computer use, television viewing, or driving automobiles have become ubiquitous in modern societies due to changes in the physical, social, and economic environments (Owen et al., 2010). These behaviours are collectively known as sedentary behaviours, which have been defined as waking activities characterized by an energy expenditure of ≤1.5 metabolic equivalents (METs) that occur whilst sitting or lying down (Tremblay et al., 2017). A MET is a unit that represents the estimate metabolic cost of an activity, with one MET corresponding to a person's resting energy expenditure (Jette et al., 1990). The use of a common unit allows researchers to categorize and compare different activities in the same continuum of energy expenditure (Figure 1). Activities can be classified into sedentary behaviour (≤1.5 METs), light-intensity physical activity (1.6-3 METs), or moderate-to-vigorous physical activity (3-6 METs for moderate intensity and ≥6 METs for vigorous intensity). Of note, sedentary behaviour is not a synonym of physical inactivity, which is a term used to identify individuals who do not meet the recommended level of regular physical activity (Tremblay et al., 2017).

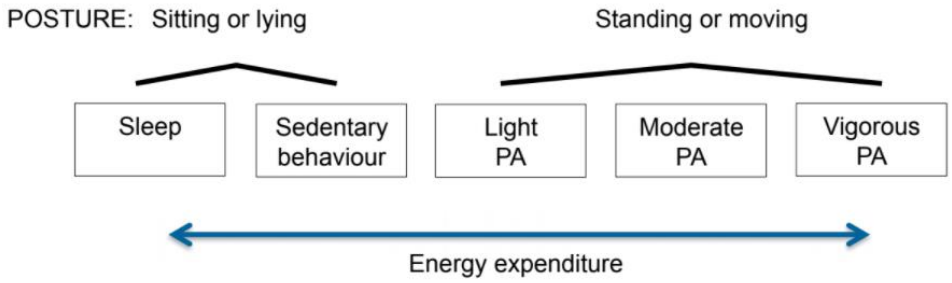

Figure 1. A depiction of sedentary behaviour and physical activity along with energy expenditure and posture continuum (from Biddle et al., 2015).

1.3 Why Does Sedentary Behaviour Matter for Health?

An energy-expenditure perspective highlights how relevant sedentary time is in the context of physical activity and health. For many individuals, time spent sedentary represents the most prevalent behaviour along the energy expenditure continuum (Donahoo et al., 2004). Device-based estimates show that adults in high-income countries spend on average 8 to 10 hours per day being sedentary (Hagstromer et al., 2010; Matthews et al., 2008), and there is evidence suggesting that the levels of sedentary behaviour are increasing. For example, Du et al. (2019) noted that on average self-reported sedentary time among US adults has increased by 42 minutes per day in the last decade. While the reasons for this trend remain unclear, it is plausible that recent changes in our social and economic environments prompt individuals to sit down for longer periods (e.g., increased number of white-collar jobs, wider use of screen-based devices and passive forms of transportation).

The development of an explicit interest in sedentary behaviour can be traced to the 1950s, where Morris et al. (1953) investigated the risk of coronary heart disease in London bus drivers (who spend most of their working hours sitting) compared with conductors (who spend most of their working hours engaged in active duties). However, it is not until the 21st century that research on sedentary behaviour has proliferated (Owen et al., 2020), with previous public health efforts mainly focused on moderate-to-vigorous physical activity. Research on sedentary behaviour now covers all phases within the behavioural epidemiology framework (Sallis et al., 2000a). This framework features a sequence of research categories about any health-related behaviour and proposes a general progression of types of studies ultimately leading to evidence-based public health interventions (Figure 2).

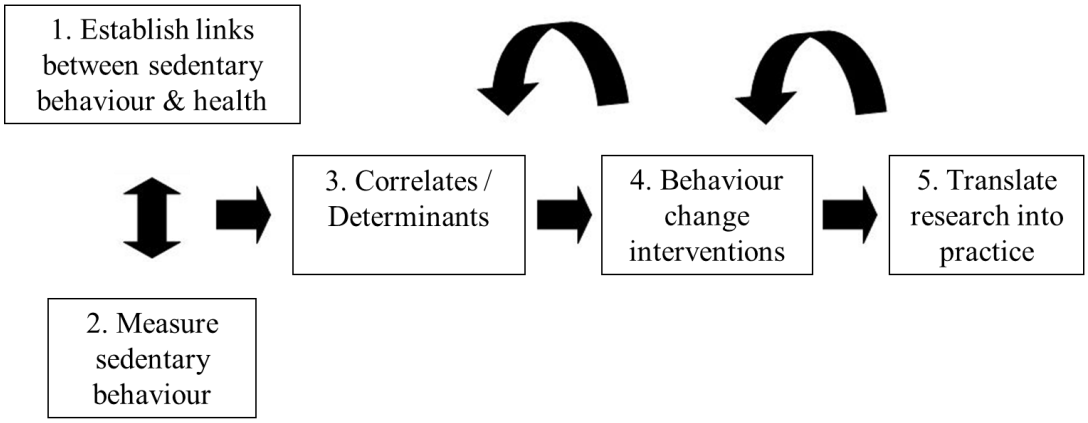

Figure 2. Behavioural epidemiology framework: Phases of evidence for population health science of sedentary behaviour (adapted from Sallis et al., 2000a).

Observational evidence from the first phase of the behavioural epidemiology framework links high levels of sedentary behaviour with an increased risk of detrimental health outcomes, such as metabolic syndrome, poorer glycemic control, diabetes, cardiovascular disease, colon and rectal cancer, and death (Cong et al., 2014; Davies et al., 2018; Edwardson et al., 2012; Ekelund et al., 2019; Greer et al., 2015; Grøntved & Hu, 2011; Lynch, 2010; McGlory et al., 2018; Patterson et al., 2018; Proper et al., 2011; Schmid & Leitzmann, 2014; Thorp et al., 2011; Wilmot et al., 2012;). In addition, sedentary behaviour has also been associated with poorer levels of mental well-being, including reduced life satisfaction (…) and an increased risk of depression, anxiety, and stress (Costigan & Parker, 2015; Hamer et al., 2010; Rebar et al., 2014; Teychenne, et al., 2015; Zhai et al., 2014). While the above studies suggest sedentary behaviour has negative effects on health, it should be noted that the evidence base is mostly cross-sectional. There is only a paucity of studies exploring the prospective associations of total and prolonged sedentary behaviour with health outcomes. In addition, most of the evidence relies on self-reported sedentary behaviour, which is prone to recall and desirability bias. The increasing use of thigh-worn accelerometers in epidemiological research is promising as it provides more accurate estimates of sedentary behaviour (Kim et al., 2015).

Animal-based and human experimental studies have investigated potential biological pathways that may contribute to explain the observed associations between sedentary behaviour and health, and whether these mechanisms might be different from those associated with moderate-to-vigorous physical activity

(Hamilton et al., 2007). For example, adiposity and metabolic dysfunction have been identified as possible biological mechanisms mediating the relationship between sedentary behaviour and cancer (Lynch, 2010). Similarly, acute periods of uninterrupted sitting have been associated with significant increases in glucose and postprandial insulin, when compared to periods of sitting interrupted with light- or moderate-intensity physical activity (Saunders et al., 2018). However, research is limited and still maturing; there remains a need to investigate potential underlying mechanisms linking sedentary behaviour to negative health outcomes (Dempsey et al., 2020).

1.4 Sedentary Behaviour, Physical Activity and Public Health Guidelines

Considerable research efforts have been directed at understanding the links between sedentary behaviour and physical activity. While the two behaviours have shown significant negative associations, the magnitude of the relationship appears to be dependent on the type of physical activity: medium to large negative associations between sedentary behaviour and light-intensity physical activity, and small negative associations between sedentary behaviour and moderate-to-vigorous physical activity (Mansoubi et al., 2014). In other words, sedentary behaviour seems to be readily displaced by light-intensity physical activity and vice versa. In contrast, an individual might be considered active by meeting moderate-to-vigorous physical activity guidelines but also spend a large portion of the day engaged in sedentary behaviours (e.g., using the computer or watching television).

Another key question is whether the negative health effects associated with high volumes of sedentary behaviour could be attenuated or even eliminated by physical activity. That is, what is the interplay between sedentary behaviour and physical activity in relation to health outcomes? Ekelund et al. (2016), in a harmonised meta-analysis including >1 million individuals, showed that physical activity can indeed eliminate the risk of all-cause mortality associated with sedentary behaviour. However, high levels of daily moderate-to-vigorous physical activity are required (60-75 minutes/day), which widely exceed current recommendations and might not be a feasible target for the general population. This has prompted researchers to provide separate moderate-to-vigorous physical activity and sedentary behaviour guidelines for public health (e.g., Australian Department of Health, 2014;

UK Department of Health, 2019). Current public health guidelines highlight the importance of reducing sedentary behaviour in favour of both increased light-intensity and moderate-to-vigorous physical activity (notably, with bouts of any duration), offering new opportunities from a public health perspective.

Unlike moderate-to-vigorous physical activity guidelines, most public health recommendations on sedentary behaviour are general and non-quantitative (e.g., sit less, move more). A notable exception is the recent Canadian 24-Hour Movement Guidelines, which integrate physical activity, sedentary behaviour, and Sleep and provide specific recommendations for each behaviour (Ross et al., 2020). In the case of sedentary behaviour, the recommendation is to limit sedentary time to 8 hours or less. These guidelines have sparked some debate on whether the evidence base is of sufficient quality to support specific behavioural targets on the 'optimal' amount of sedentary behaviour (Stamatakis & Bauman, 2020). A point of consensus, however, seems to be that associations of daily sedentary behaviour and long-term health outcomes are not linear: high volumes of sitting seem to be particularly detrimental to health (especially among those that are most inactive). For example, Patterson et al. (2018) found positive and non-linear associations between self-reported sedentary time and cardiometabolic/mortality outcomes across 34 studies (n = 1,331,468). A threshold of between 6 and 8 h per day of total sitting was identified, above which the mortality risk is increased. In relation to accelerometer-assessed sedentary behaviour, Ekelund et al. (2019) also showed evidence of a non-linear association between time spent sedentary and risk of death across eight studies (n = 36,383). Authors found a statistically significant higher mortality risk for daily sedentary times of 9.5 or more hours.

In addition to the total levels of sedentary time, it is also important to consider the patterns in which it is accumulated. Public health guidelines state that individuals should minimise sitting time and introduce regular breaks from long periods of sitting (e.g., Australian Department of Health, 2014; UK Department of Health, 2019; Ross et al., 2020). This is due to epidemiological evidence suggesting that prolonged, uninterrupted bouts of sitting are particularly detrimental to health (Bellettiere et al., 2019; Diaz et al., 2017). Similarly, experimental studies have shown that increased breaks in sitting time are associated with favourable musculoskeletal and cardiometabolic health outcomes (Benatti & Ried-Larsen, 2015;

Todd et al., 2007). However, what constitutes an effective break, in terms of mode, duration, and frequency, is still a current topic of debate (Larsen et al., 2017; Stamatakis et al., 2019). Preliminary evidence suggests that light-intensity physical activity breaks may provide increased benefits over standing-breaks (Bailey & Locke, 2015). Moreover, the characteristics of the sample may also play an important role in determining whether breaks are associated with health risk reductions, especially with respect to participants' age and level of physical activity (Benatti & Ried-Larsen, 2015) or presence of chronic conditions (Henson et al., 2016).

1.5 Sedentary Behaviour in University Students

As reflected in the behavioural epidemiology framework, a key step in the development of a population health science of sedentary behaviour is the identification of correlates (i.e., the variables associated with sedentary behaviour). Understanding the influences on sedentary behaviour is critical to inform interventions and identify population subgroups that are particularly sedentary (Bauman et al., 2002). Several correlates have been associated with sedentary behaviour, including age, socio-economic status, neighbourhood walkability, having children, or screen devices ownership (O'donoghue et al., 2016; Prince et al., 2017). A key variable that explains substantial variation in sedentary time among working-age adults is 'occupation' (Loyen et al., 2016), with white-collar workers reporting higher levels of sedentary behaviour than other occupational groups (e.g., manual workers). Indeed, most of the sedentary behaviour and public health research among adults focuses on desk-based office workers (Gardner et al. 2016), which in one sense brings the physical activity field back to the seminal research from Morris and collaborators (1953).

Similar to office workers, university students spend most of their waking hours behind a desk, either studying, completing assignments, or attending lectures. Data from the systematic review and meta-analysis included in the present thesis suggests that university students accumulate higher levels of sedentary behaviour than the global average, thus providing a rationale for sedentary behaviour reduction efforts in the university setting (see Study 2 for further consideration on this topic). However, few studies have focused specifically on the sedentary behaviour of university students (Cotten & Prapavessis, 2016). This constitutes an important

research gap for distinct reasons. First, there is evidence from young adult populations suggesting that high levels of sedentary behaviour are associated with negative health outcomes (Table 1). Second, the university years serve as an important period for the development of a lifelong healthy lifestyle, with many health behaviours established during adolescence and young adulthood (Nelson et al., 2008). This is particularly important for sedentary behaviour as university students are likely to transition into a desk-based occupation upon graduation, thus being potentially exposed to high levels of work-related sedentary behaviour. Third, the number of university students in high-income countries comprise a large proportion of the young adult population. For example, there are 1.3 million students enrolled at a higher education institution in Australia, with this number expected to increase in the coming decades (Edwards & van der Brugge, 2012). Last, university students are more likely to adopt leadership roles, where they may influence others' health behaviours and subjective norms (Leslie et al., 1999).

Table 1. Associations between sedentary behaviour and health outcomes in young adults.

Health-related outcomes	Study design	Findings
Bone health	Systematic review (Koedijk et al., 2017)	Negative association between device-based sedentary behaviour and lower extremity bone outcomes
Thoracic spine mobility	Observational study (Heneghan et al., 2017)	Positive association between self-reported sedentary behaviour and reduced thoracic spinal mobility
Aerobic fitness	Systematic review (Chinapaw et al., 2011)	Negative association between self-reported sedentary behaviour and aerobic fitness
Depression symptoms	Observational study (Kandola et al., 2017)	Positive association between device-based sedentary behaviour and depression symptoms
Life satisfaction	Experimental study (Edwards & Loprinzi, 2017)	Significant group x time interaction indicating decreased life satisfaction in the 'high sedentary behaviour' group

Anxiety	Experimental study (Edwards & Loprinzi, 2017)	Significant group x time interaction indicating increased anxiety in the 'high sedentary behaviour' group

1.6 Reducing Sedentary Behaviour in the University Setting

In recent years, there has been an increased number of intervention studies targeting sedentary behaviour in university students. Cotten and Prapavessis (2016) conducted a randomised control trial and found small-to-moderate effects favouring the effectiveness of a text message-based intervention in increasing university students' non-sedentary behaviours (especially light-intensity physical activity). In a pilot randomised control trial, Sui and Prapavessis (2018) provided evidence for the potential of an intervention to increase break frequency during occupational (student) sedentary behaviour. More recently, Dillon et al. (in press) reported significant reductions in student-related sedentary behaviour for an intervention combining a Health Action Process Approach with frequent text messages. Some other interventions have focused on introducing environmental changes. For example, Jeromea et al. (2017) tested the effects of introducing sit-to-stand desks into a university classroom on student's sitting and standing behaviours. Their findings support sit-to-stand desks as an approach to reduce sedentary behaviour in university classrooms. Mnich et al. (2019) found that placing decisional cues on campus (i.e., posters and table plaques) is an effective strategy to decrease university student's sedentary behaviour and promote active alternatives. In addition, Moulin et al. (in press) reported a significant reduction in device-based and self-reported sedentary behaviour in undergraduate students provided with a mobile standing desk.

While the above-mentioned studies were somewhat successful in changing their respective target behaviours in the short-term, a limitation is that interventions were often not informed by a particular theory of behaviour change or, at least, theoretical guidance was not explicitly reported (this applies specially to the interventions focused on introducing environmental changes). However, incorporating theory to behaviour change interventions is viewed as good practice (Glanz & Bishop, 2010). For example, the UK Medical Research Council emphasises the application of theory as an essential step in intervention design and evaluation (Craig et al., 2008). The rationale is that, to develop an effective

intervention, it is important to have a clear understanding of what the target behaviour is and how behaviour change works, so the relevant mechanisms of change (i.e., mediators) can be appropriately targeted (Michie et al., 2008). Moreover, applying theory allows researchers to determine how the intervention achieved its results, facilitating the process evaluation of trials. For example, an intervention might have failed because the techniques employed did not affect the hypothesised mediator or because the (successfully influenced) mediator had no effect on behaviour, thus opening the door for further theory optimisation (Rothman, 2004).

Although theory adoption is widely advocated, the evidence as to whether theory-based interventions are more effective than those that are not is somewhat contradictory. Some systematic reviews and meta-analyses have found interventions grounded in a particular theoretical framework to be more effective (Glanz & Bishop, 2000; Gourlan et al., 2015), while in contrast others have shown little or no differences (Gardner et al., 2011; Stephenson et al., 2000). There are many reasons that may explain this mixed evidence. First, in some cases, a theory can be used but not explicitly reported (Michie & Prestwich, 2010). Second, evidence suggests theory is often poorly implemented. A review analysing the application of theory in intervention studies found that very few linked behaviour change techniques to theoretical constructs/mediators or used theory to tailor the intervention and select recipients (Prestwich et al., 2014). That is, theory was in most cases only loosely referred to, rather than carefully applied to develop or evaluate interventions. Third, even when a model or theory is chosen to guide the intervention, a single model or theory might not be sufficient to cover the full range of possible influences of behaviour (Michie et al., 2011). It has been argued that behaviour cannot be fully explained by a particular theory of behaviour change and it may be more appropriate to utilise a range of comprehensively mapped theoretical constructs (Abraham, 2015; Hagger & Chatzisarantis, 2014). For example, the theory of planned behaviour or the health belief model (as well as other leading theoretical frameworks in the area of health promotion) focus on controlled processes (i.e., conscious, slow, effortful, and volitional) while ignoring automatic processes (i.e., nonconscious, fast, effortless, and unintended; Sniehotta et al., 2014; Marteau, 2018). The habitual and environmentally reinforced nature of sedentary behaviour, however, suggests that

automatic processes (e.g., nudges, habits) are also important influences for this particular behaviour, and thus should be incorporated in behaviour change interventions (Maher & Conroy, 2016). Similarly, most theories commonly used in public health interventions focus on individual rather than wider environmental and social variables, yet research indicates that interventions simultaneously targeting variables at different levels are more effective (Abraham et al., 2009).

1.7 The Behaviour Change Wheel: A Guide to Designing Interventions

In an attempt to improve intervention development and overcome the above-mentioned pitfalls to theory implementation, the BCW (Michie et al., 2011) provides a theoretically driven framework that incorporates multiple theories of behaviour change. The BCW was developed after a comprehensive evaluation of 19 frameworks of behavioural interventions, which were evaluated according to three criteria: coherence, comprehensiveness, and a clear link to an overarching model of behaviour. It was concluded that none of the existing frameworks met these criteria, lying the foundation for a new method of behaviour change.

The COM-B model underpins the BCW and specifies three conditions for a given behaviour to occur (Michie et al, 2014). Capability refers to the physical and psychological ability to perform the behaviour, Opportunity to the physical and social environment that enables the behaviour, and Motivation to the reflective and automatic mechanisms underlying the behaviour. By using the TDF these three components can be sub-divided into 14 theoretical domains from a synthesis of 33 theories relevant to behaviour change (Cane et al., 2012). Nine intervention functions and seven policy categories complete the wheel and help identify what needs to change for the behaviour to occur (Figure 3).

The BCW has underpinned the development of interventions targeting a broad range of different health-related behaviours, including sedentary behaviour (Munir et al., 2018), physical activity (Norris et al., 2016), eating behaviours (Atkins & Michie, 2015), smoking (Tombor et al., 2016), alcohol consumption (Garnett et al., 2016), or condom use (McCarthy et al., 2016). While other intervention development frameworks are available in the literature, the BCW is the only one that includes a model of behaviour as a core element, and it is broad enough to cover the full range of factors that potentially affect behaviour.

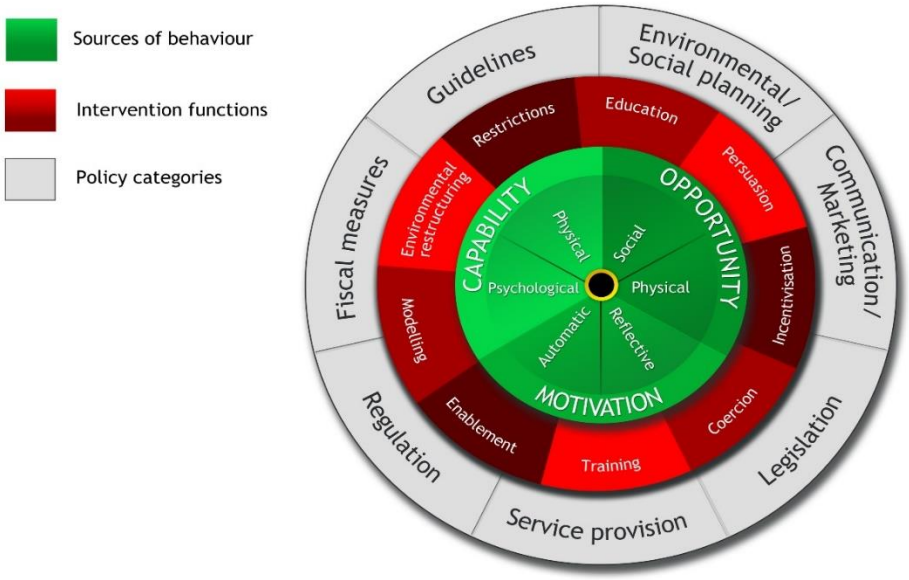

Figure 3. The Behaviour Change Wheel (Michie et al., 2014).

Intervention development using the BCW follows a standardised approach, comprising of three main stages: (i) understanding the target behaviour; (ii) identifying intervention functions; and (iii) identifying content and implementation options. These stages are sub-divided into key steps (Figure 4). Although it is usual that one stage informs the subsequent one, feedback loops can be used to refine previous stages. The first stage enables the intervention developers to specify the target behaviour, followed by a practical method on how to identify what needs to be changed for the target behaviour to occur using the COM-B model, known as "behavioural diagnosis" (Is it greater Capability, more Opportunity, or stronger Motivation that is required to achieve change?). Based on the results from the 'behavioural diagnosis', stage 2 provides theoretical guidance on which intervention functions and supporting policies are expected to be effective for a given behaviour, context, or target population (e.g., are environmental changes required? Does target population need to receive education, incentives, training?). Having identified relevant intervention functions and policy categories, stage 3 consists of identifying intervention content (e.g., which Behaviour Change Techniques serves the interventions functions best?) and which mode of delivery is most appropriate (e.g., face-to-face, app, telephone calls).

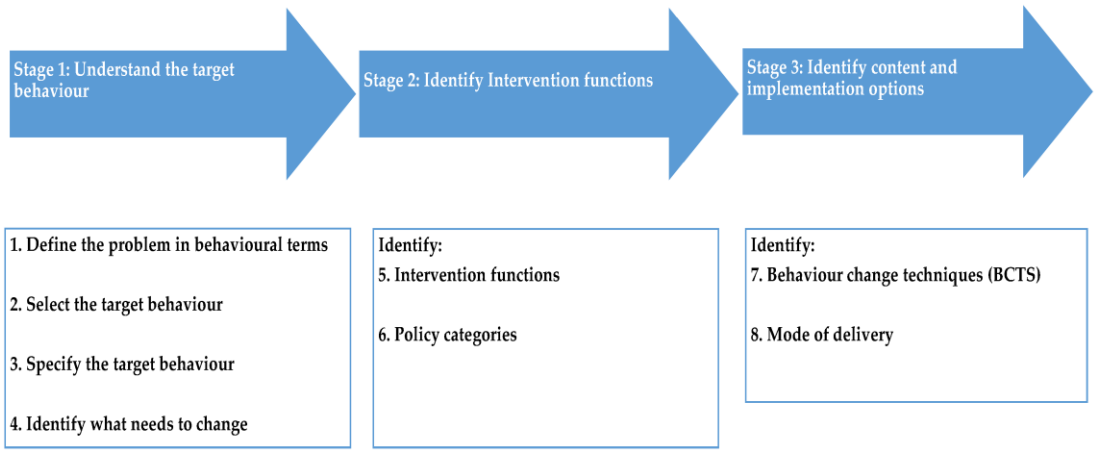

Figure 4. The Behaviour Change Wheel intervention design process (Michie et al., 2014).

1.8 Summary and Aims

Current evidence indicates that accumulating high levels of total and prolonged sedentary behaviour is a risk factor for multiple negative health-related outcomes. For one distinctive subgroup of the young adult population – university students – the prevalence of sedentary behaviour appears to be higher than the global average. Initiatives are thus needed in the university setting to help students reduce their time spent sedentary and enhance movement patterns. However, current sedentary behaviour interventions among university students are limited and often lack theoretical guidance. To develop effective behaviour change interventions, it is important to understand the nature of the behaviour to be changed and implement a systematic method for characterising interventions that can make use of this understanding.

The overall aim of this PhD project was to develop and pilot an intervention aimed at reducing and breaking up sedentary behaviour in university students. The BCW guided the set of steps and activities required for the intervention development. In the following chapters, these activities and accompanied research methods are detailed.

Chapter 2 Understanding the Target Behaviour

2.1 Overview of the Chapter

Stage 1 of the BCW details four steps that lay the groundwork for understanding what needs to change for the desired behaviour to occur. First, it is important to define the overall health problem in behavioural terms, being specific about the behaviour and the population. For example, weight loss is not a behavioural target but an outcome; reducing calorie intake and increasing physical activity are behavioural targets, which can vary in their level of specificity (e.g., increasing overall physical activity vs walking to and from work). In the present project, the problem was defined as the health risks associated with high levels of total and prolonged sedentary behaviour. Second, steps 2 and 3 involve selecting the behaviour to target among all possible alternatives and specifying it in detail, including parameters such as frequency, duration, or context. This step is illustrated in Table 2.

Table 2. Characteristics of the target behaviour 'reducing and breaking up sedentary time'.

Target behaviour	Reducing and breaking up sedentary time
***Who* needs to perform the behaviour?**	University students
***What* do they need to do differently to achieve the desired change?**	Substitute and break up sedentary behaviour with standing or, ideally, any form of light-intensity physical activity (Sit less, move more, more often)
***When* do they need to do it?**	During waking hours, including leisure (e.g., socialising, watching TV) and academic activities (e.g., studying, writing assignments)
***Where* do they need to do it?**	On any premises where these activities occur (e.g., home, library).

How often **do they need to do it?**	In contrast to moderate-to-vigorous physical activity guidelines, sedentary behaviour guidelines are broad and non-quantitative due to the absence of sufficient evidence to support specific recommendations (Young et al., 2016). However, previous studies reporting positive health outcomes have prompted breaks ranging from two-four minutes in length every 20-30 minutes of sitting (Dunstan et al., 2012; Howard et al., 2013). In our study, university students were encouraged to minimise overall time spent sitting and break up their sedentary time every half an hour, whenever possible.
With whom **do they need to do it?**	Alone or with others.

The fourth and last step consists of using the COM-B model to identify what it is about the target population or the environment that the intervention needs to address to achieve change. That is, does the person has the necessary knowledge, skills or physical strength to perform the behaviour (capability)? Is there a conducive physical and/or social environment for the behaviour (opportunity)? And, is the person motivated enough to perform the behaviour among other alternatives (motivation)? All three elements influence whether the desired behaviour occurs or not and thus should be assessed when designing the intervention (Atkins et al., 2017). Drawing a parallel with the medical field, the BCW describes this step as 'behavioural diagnosis'. It is hypothesised that a good behavioural diagnosis is more likely to lead to effective interventions, because it is clear which mediators of change need to be targeted. While this might seem like an obvious step, interventions are not always designed based on a thorough analysis of the behaviour and its determinants, but on personal experience ('common sense') or a favoured theoretical approach (West & O'Neal, 2004).

Several resources can be used to obtain a clearer picture of the behaviour and the factors influencing it. For example, literature reviews, questionnaires, observation, interviews, focus groups, or expert opinion. While several studies investigating the variables associated with sedentary behaviour in university students were identified, the literature had yet to be systematically reviewed. Thus, a review

on the correlates of sedentary behaviour in university students was planned as Study 1. The main aim was to identify population-specific correlates of sedentary behaviour to inform future intervention development (modifiable correlates; mediators), as well as signal subgroups of students at risk of being excessively sedentary (non-modifiable correlates; moderators). A second approach to pinpoint factors influencing sedentary time using evidence synthesis methods consisted of gathering the literature on the levels of sedentary behaviour in university students and conducting heterogeneity analyses, to identify variables explaining variation in sedentary behaviour (Study 2 – systematic review and meta-analysis). Last, Study 3 featured a qualitative study aimed at exploring theory-based factors affecting prolonged sedentary behaviour, grounded on the COM-B and TDF. These three studies are presented below in their published version, together with a brief statement on how each publication contributes to the advancement of the research area.

2.2 Study 1: Correlates of Sedentary Behaviour in University Students: A Systematic Review

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Review Article

Correlates of sedentary behaviour in university students: A systematic review

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ABSTRACT

High levels of sedentary behaviour are associated with negative health-related outcomes. However, there is limited evidence on the variables influencing sedentary behaviour in university students. The aim of this systematic review was to identify the intrapersonal, interpersonal, environmental, and time correlates of sedentary behaviour in university students. Records from 12 electronic databases were screened by two independent reviewers. Inclusion criteria included: (i) peer-reviewed articles written in English, Spanish, or French; (ii) studies including undergraduate or postgraduate university students; (iii) studies reporting on the association between sedentary behaviour and at least one variable. The protocol is registered in PROSPERO (CRD42017074198). A total of 126 studies published between 1994 and 2017 met the inclusion criteria. The primary measure of sedentary behaviour was self-reported screen time (61%), followed by total sitting time (28%). Most studies were cross-sectional (86%). After excluding high risk of bias studies (58%), only three intrapersonal variables were sufficiently investigated (≥4) to determine an association with sedentary behaviour: physical activity (negative association with sitting time), obesity markers (indeterminate associations with TV viewing), and gender - female (null associations with total sitting time and screen time). Overall, most of the reported correlates of sedentary behaviour were intrapersonal, non-modifiable factors. Further research on modifiable correlates covering all socio-ecologic levels is required to inform future intervention development. In addition, longitudinal studies are needed to enable the identification of determinants. Improvements in designing and reporting future studies are recommended to help strengthen the available evidence and facilitate future reviewing efforts.

1. Introduction

Sedentary behaviours – defined as any waking activity characterized by an energy expenditure ≤1.5 metabolic equivalents (METs), while in a sitting, reclining, or lying posture (Tremblay et al., 2017) – have become more and more prevalent in modern societies due to changes in the physical, social, and economic environments (Owen et al., 2010). Evidence suggests that high levels of sedentary behaviour are associated with detrimental effects on health and wellbeing, including an increased risk of colon and rectal cancer (Cong et al., 2014; Schmid and Leitzmann, 2014), metabolic syndrome (Greer et al., 2015), depression (Teychenne et al., 2010; Vallance et al., 2011), diabetes, cardiovascular disease, and mortality (Grøntved and Hu, 2011; Katzmarzyk et al., 2009; Wilmot et al., 2012). Importantly, the health risks of excessive sedentary behaviour have shown to be somewhat independent of reporting a recommended level of moderate-to-vigorous physical activity (e.g., Katzmarzyk et al., 2009; Thorp et al., 2011). A recent meta analyses showed that only a high level of daily moderate-to-vigorous physical activity (60–75 min/day) appeared to attenuate the risk of all-cause mortality associated with high levels of sedentary behaviour (Ekelund et al., 2016).

The health risks associated with high volumes of sedentary behaviour have been documented across the life span, from school-aged children (Carson et al., 2016), to working-aged (Van Uffelen et al., 2010) and older adults (Stamatakis et al., 2012). While sedentary behaviour and public health research among working-aged adults concentrates largely on office workers (Gardner et al., 2016), university students are also a population sub-group at risk of being sedentary as a significant proportion of their time is spent studying or in class (Cotten and Prapavessis, 2016). Although limited, preliminary evidence exists

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suggesting that undergraduate students are highly sedentary (Farinola and Bazán, 2011; Rouse and Biddle, 2010), and that their sedentary behaviour levels equal or even surpass those of desk-based workers (Moulin and Irwin, 2017). For example, a cross-sectional study conducted in Canada concluded university students spend an average of 11.65 h of self-reported sedentary time per weekday, with most of these hours (6.18) being dedicated to university-related sedentary behaviours (Prapavessis et al., 2015).

The scarcity of research on university students leaves an important gap in the literature on adult sedentary behaviour for at least three reasons. First, the number of university students in developed countries constitutes an important portion of the young adult population and a substantial increase is expected in the future (Dragoescu, 2013; Universities, 2017). Second, university students might adopt roles such as teacher or health professional where they may influence social norms and others' health behaviours (Leslie et al., 1999). Third, the university is a critical period for the development of future life patterns; many adult health-related behaviours are established during late adolescence and early adulthood (USDHHS, 2011).

The 'behavioral epidemiology' framework (Sallis et al., 2000a) proposes that identifying correlates (i.e., the variables associated with the target behaviour) is a necessary step prior to developing interventions designed to change behaviour. Indeed, behaviours are often not changed by the intervention itself, but by a change in one or more correlates of the behaviour, which act as 'mediators' of change (e.g., self-efficacy, social support; Baron and Kenny, 1986; Bauman et al., 2002). Non-modifiable correlates (or 'moderators'), such as age or gender, may assist in identifying sub-groups at risk of being excessively sedentary (e.g., Lakerveld et al., 2017).

Among the different theories that can be used to structure the study of correlates, the socio-ecological model has been extensively used in reviews investigating what variables influence physical activity (Bauman et al., 2012) and, most recently, sedentary behaviour (O'Donoghue et al., 2016). The socio-ecological model posits that behaviour is shaped by a dynamic interrelation of variables at multiple levels (McLeroy et al., 1988; Sallis et al., 2008), including intrapersonal (e.g., attitudes, ethnicity), interpersonal (e.g., modelling, social support), physical environmental (e.g., neighbourhood characteristics, building design), and time variables (e.g., day of the week, time of day). Previous systematic reviews have explored the correlates of adult sedentary behaviour (O'Donoghue et al., 2016; Prince et al., 2017; Rhodes et al., 2012). However, to our knowledge, no known specific review has focused on university students. Such a review may be helpful for identifying population-specific correlates of sedentary behaviour and informing future interventions. Therefore, the primary aim of the present study is to systematically review the literature on socio-ecological correlates of total and domain-specific sedentary behaviours in university students.

2. Methods

The research protocol of this study is registered in PROSPERO, an international prospective register of systematic reviews (registration number: CRD42017074198). The PRISMA guidelines were followed (Moher et al., 2009).

2.1. Search strategy

The following 12 electronic bibliographic databases were searched: EBSCOhost MegaFile Ultimate (including Academic Search Ultimate, CINAHL with Full Text, Education Research Complete, ERIC, PsycARTICLES, Psychology and Behavioral Sciences Collection, PsycINFO, and SPORTDiscus with Full Text), Web of Science (including Web of Science Core Collection and MEDLINE), Scopus, and SciELO. Search alerts were set for each database and maintained until the final analyses (January 2018). The search strategy was developed with the assistance of a research librarian and combined the term 'student' with variations on the terms "university" (e.g. undergraduate, higher education), and "sedentary behaviour" (e.g. sitting, screen time). As a more detailed example, the search strategy for EBSCOhost MegaFile Ultimate is available as online supplementary material. Terms in the search were adapted where necessary to meet different database search criteria. In addition to the database search, reference lists of included studies were manually screened to identify studies.

2.2. Inclusion criteria

Articles were included if they met the following criteria: 1) published in a peer-reviewed journal in English, Spanish, or French; 2) included university students; and 3) investigated the association between at least one potential correlate and sedentary behaviour. Inclusion was not restricted by study design or publication date. University students were defined as undergraduate or postgraduate ('graduate') students, regardless of their mode of enrolment (e.g., full-time, part-time, on-campus, or online). Studies with samples other than undergraduate or postgraduate students were excluded (e.g., students at high school, vocational school, or school of music). Studies with special populations (e.g., students with disabilities) were excluded in order to produce findings generalizable to the broader population. In terms of types of sedentary behaviour, one or more of the following were acceptable: total sedentary or sitting time (e.g., minutes/hours per day), screen time (e.g., television, computer, mobile phone, or video games), occupational sedentary behaviour (e.g., attendance to lectures, private study time), or passive transportation (e.g., driving from/to the university). Sedentary behaviour was assessed either through self-reported or accelerometer-based measures. If sedentary behaviour was reported in terms of frequency rather than amount of time (e.g., TV viewing during X days per week), studies were excluded. Valid measures of association between a potential correlate and sedentary behaviour in quantitative studies included correlations, differences between groups, regression estimates, and odds ratios.

2.3. Selection process

The study selection process consisted of three phases: first, two reviewers (OC and GB) independently screened articles based on title and abstract to assess whether they met the inclusion criteria. In cases of doubt or disagreement, articles were included in the next phase. Second, the full texts of all articles selected in the initial phase were screened by two independent reviewers (OC and GB). Inclusion checklists were completed for each study, along with details on why exclusion occurred. Third, the reference list of each included study was fully reviewed to ensure that no relevant articles were missed. Any disagreement between reviewers in phases two and three was resolved by discussion (87% agreement in initial screening). If required, disagreement was resolved through a consensus discussion with a third reviewer (SJHB).

2.4. Data extraction

Two reviewers (OC and GB) independently extracted data from the included studies onto a standardized pre-piloted data extraction form. Discrepancies were identified and resolved through discussion (93% agreement in initial data extraction), with a third researcher mediating where necessary (SJHB). Data extracted included: (i) publication details; (ii) study design, (iii) sample characteristics, (iv) measurement of sedentary behaviour; (v) type of sedentary behaviour; (vi) correlates investigated; and (vii) significant findings.

2.5. Data analysis

A narrative synthesis was used to describe reported associations

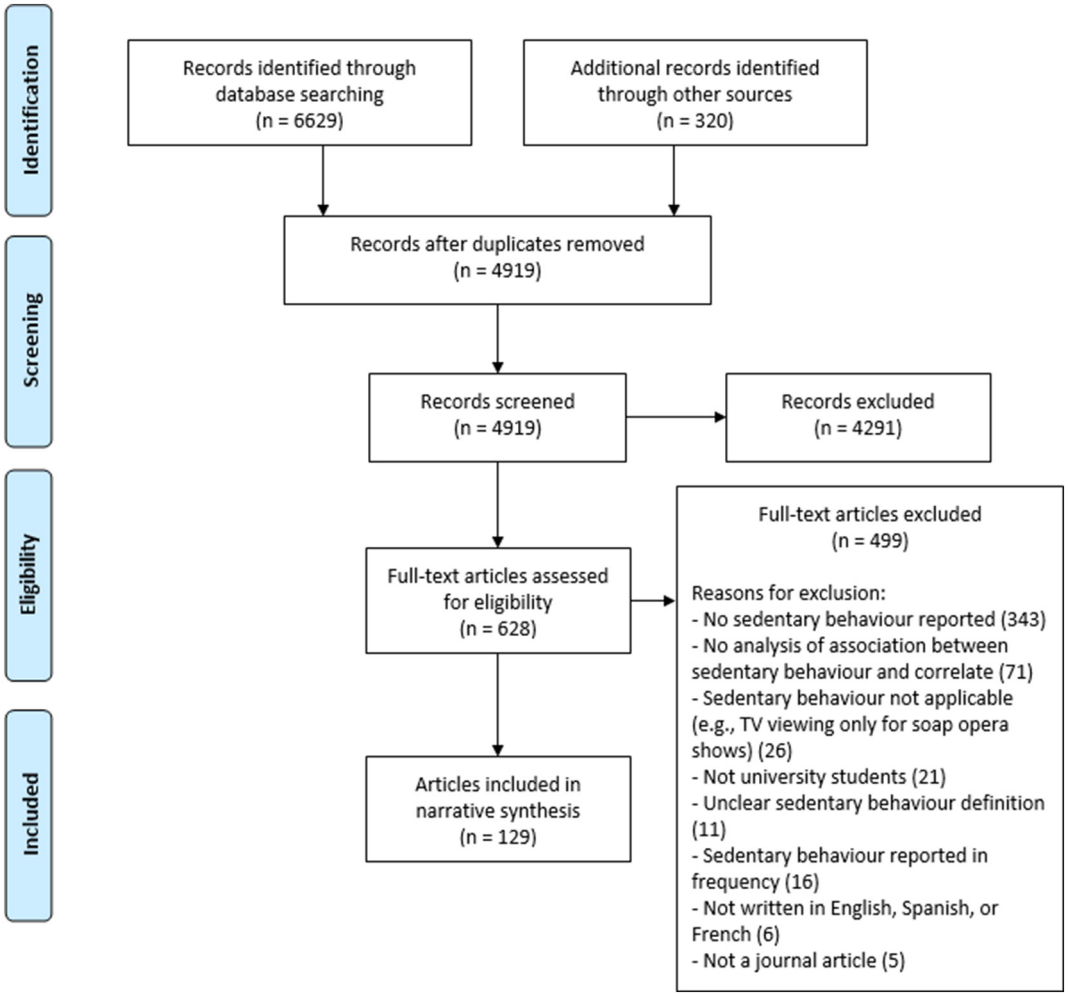

Fig. 1. Flow chart for the articles included in the systematic review of correlates of sedentary behaviour in university students.

between sedentary behaviour and potential correlates in observational studies (prospective cohorts and cross-sectional). Correlates were grouped according to different levels from the social ecological model, including intrapersonal (e.g., attitudes, ethnicity), interpersonal (e.g., modelling, social support), environmental (e.g., neighbourhood characteristics, building design), and time variables (e.g., day of the week, time of day). The methodology for classifying strength and direction of associations follows a model provided by Sallis et al. (2000b). In this model, the percentage of findings supporting the hypothesized association between a correlate and a given sedentary behaviour determines its consistency. Specifically, associations were coded '0' (null; 0%–33% of studies supporting the association), '?' (indeterminate; 34%–59% of studies supporting the association), or '+' or '−' (positive/negative; 60%–100% of studies supporting the association). A positive association occurs when the values of one variable tend to increase as the values of the second variable increase. In contrast, two variables have a negative association when the values of one variable tend to decrease as the values of the second variable increase. For categorical variables, a positive/negative association is understood in the context of differences between groups (categories). For example, a positive association between gender (female) and total sitting time means that females reported to sit more than males. Potential correlates were grouped in four groups (i.e., interpersonal, intrapersonal, environmental, or time), aligning with the socio-ecological model (Sallis et al., 2008). In addition, some variables were clustered thematically (e.g., *obesity markers* including BMI, fat percentage, and abdominal obesity). Only potential correlates investigated four or more times were considered for discussion. These variables were coded '00', '??', '++', or '−−' as appropriate. A quantitative synthesis (meta-analysis) was deemed inappropriate due to the heterogeneity of sedentary behaviour measures employed and the limited amount of studies investigating the same variables.

2.6. Risk of bias

The studies' risk of bias was assessed using a version of the Cochrane Collaboration's Tool for Assessing Risk of Bias (Higgins et al., 2011) adapted for observational studies. The modified version has been employed previously in Poitras et al. (2016) and Prince et al. (2017). Observational studies were assessed for potential sources of bias, including selection bias (sampling method), performance bias (measurement of sedentary behaviour), detection bias (measurement of correlate), attrition bias (completeness of outcome data), selective reporting bias (selective outcome reporting), and other bias (control for confounding). Each item was marked as high, low, or unclear risk of bias according to pre-specified criteria (risk of bias instrument available as online supplementary material). Two independent reviewers (OC and GB) assessed the risk of bias, resolving any conflicting results by discussion (84% agreement in initial risk of bias assessment). If required, disagreements were resolved via team discussion with a third reviewer (SJHB). A composite risk of bias score for each study was then calculated by summing the total number of criteria marked 'low risk of bias'. When three or more of the six risk of bias criteria were met, studies were classified as having a low risk of bias. The rest of the studies were

Table 1
Potential correlates of sedentary behaviour in university students investigated in ≥4 low risk of bias studies.

Potential correlates	Total sitting time	Screen time (TV)	Screen time (TV + computer + video games)
Gender (female)	0 (3/13) +: Bergier (2017); Hongjun (2017)[a]; Rubio-Henao (2016)[a] −: Ruiz et al. (2012)[a] 0: Atalay (2014)[a]; Bergier (2012)[a]; Camargo (2009)[a]; Farinola (2011); Felez-Nobrega (2017); Malmborg (2017)[a]; Mestek (2008)[a]; Peltzer (2014a)[a]; Yan (2007)		0 (0/4) 0: Felez-Nobrega (2017); Feng (2014); Hidalgo-Rasmussen (2013); Kritsotakis (2016)
Physical activity (MET min/week)	− (5/5) −: Mantilla-Toloza (2008)[a]; Quartiroli (2014)[a]; Camargo (2009)[a]; Mantilla-Toloza (2008)[a]; Peltzer (2014a)[a]		
Obesity markers[c]		? (4/7) +: Deliens (2013b)[a]; Thomson (2008); Pullman (2009); de Souza (2014)[b] 0: Hamam (2016); Musaiger (2003); Deliens (2013b)	

Abbreviations: '+' positive association, '−' negative association, '0' null association, '?' indeterminate association. The methodology for classifying strength and direction of associations follows a model in which the percentage of findings supporting the hypothesized association between a correlate and a given sedentary behaviour determines its consistency (Sallis et al., 2000b). Specifically, associations were coded '0' (null; 0%–33% of studies supporting the association), '?' (indeterminate; 34%–59% of studies supporting the association), or '+'/'−'(positive / negative; 60%–100% of studies supporting the association).

[a] Sedentary behaviour measured only during weekdays.

[b] Sedentary behaviour measured only in males.

[c] Obesity markers include BMI, overweight, obesity, abdominal obesity, waist circumference, waist-to-height ratio, and fat percentage.

classified as high risk of bias, unless four or more criteria presented an unclear risk of bias due to incomplete reporting. In these cases, studies were classified as unclear risk of bias. The analysis of correlates was restricted to studies at low risk of bias. A sensitivity analysis was performed to explore how conclusions might be affected if all studies were included.

3. Results

3.1. Description of studies

A total of 129 articles representing 126 original studies met the eligibility criteria (Fig. 1). Studies were published between 1994 and 2017 in English (89%) or Spanish (11%), with the majority of studies conducted over the last 5-years (64%). Data from 186,630 participants were included (Median: 278 participants per study; Interquartile range: 146–624). Studies were from North America (30%), Europe (25%), Asia (21%), South America (9%), Africa (8%), and Australia (3%). All studies apart from one (qualitative) were observational, including cross-sectional (86%) and cohort (13%) studies. A detailed overview of all included study characteristics is presented as online supplementary material.

3.2. Risk of bias assessment

Based on the composite risk of bias score, a majority of studies was classified as high risk of bias studies (58%). The remainder was classified as low risk of bias studies. In relation to the risk of bias per each criterion, over half of the studies (63%) had a high risk of selection bias, as these included convenience (non-probabilistic) samples. Many studies (69%) had a high risk of performance bias, given that in most cases sedentary behaviour was measured through a non-validated tool. In contrast, the risk of detection bias was low for most studies (75%), which was largely attributed to the fact that the majority used validated tools for measuring potential correlates or these were basic demographics. Over one third of the studies (37%) presented < 10% of missing data (or low loss of participants for cohort studies) and were thus coded as low risk of attrition bias. Notably, risk of attrition bias was unclear for almost half of the studies. Most authors did not report missing data. Selective reporting bias was predominantly low (80%); the studies coded as high risk of selective reporting bias (16%) were in most cases secondary analyses of a pre-existing data set. Finally, two thirds of the studies (66%) had high risk of confounding bias, meaning that authors did not apply a statistical method to adjust for potential confounding factors. Detailed risk of bias results are presented as online supplementary material.

3.3. Measurement of sedentary behaviours

Most studies (94%) based their measurements exclusively on self-reported sedentary behaviour (e.g., questionnaires or inventories). The remainder relied on either accelerometer-based measures of sedentary behaviour (4%) or a combination of both self-reported and accelerometer-based measurements (2%). The primary measure of sedentary behaviour was screen time (61%), followed by total sedentary behaviour or sitting time (28%), occupational sedentary behaviour (9%), and passive transportation (2%).

3.4. Correlates

Across the 125 observational studies, 189 variables were examined as potential correlates. Of those, 171 (91%) were investigated just once each, six (3%) were investigated twice, seven were investigated thrice (4%) and five (2%) were investigated four or more times. Studies examined a median of two potential correlates (range 1–13). Of all potential correlates, 144 variables were classified as intrapersonal (e.g. age, self-rated health), 28 as interpersonal (e.g. seeing others in the neighbourhood exercise, being in a relationship), 13 as environmental (e.g. country income, traffic), and four as time correlates (e.g. day of the week, course of the year).

After excluding studies at high risk of bias, three intrapersonal correlates were found to have been studied in a sufficient number of studies (≥4) to determine an overall association: gender, physical activity, and obesity markers (Table 1). Of note, none of the correlates was investigated three times after excluding high risk of bias studies. If all studies were included, two additional variables would have been examined frequently enough (≥4) to determine associations: musculoskeletal symptoms (positive association with computer use) and academic performance (negative association with video games use). Complete results from the sensitivity analysis and an overview of all

variables investigated are available as online supplemental material.

4. Discussion

The aim of this study was to systematically review the literature on correlates of sedentary behaviour in university students using the socio-ecological framework. Following the criteria provided by Sallis et al. (2000b) and after excluding high risk of bias studies, overall associations between three intrapersonal correlates and various sedentary behaviour domains could be established.

Gender (female) was found to have a null association with total sitting time and screen time (combining TV, computer, and video games). These findings are similar to those found by Rhodes et al. (2012) in a systematic review on correlates of sedentary behaviour in adults. However, associations between gender and other sedentary behaviour domains could not be examined due to the lack of sufficient studies. There is evidence in the literature of a positive relationship between being male and use of video games across students of different ages (Greenberg et al., 2010). Similarly, some studies suggest that females tend to spend more time studying and using mobile phones than males (e.g., Fountaine et al., 2011; Musaiger et al., 2017). Further research is needed to determine the role of gender in the different sedentary behaviour domains. This information may be used for targeting different behaviours between genders.

In terms of total sitting time and physical activity, all studies reported a negative (inverse) association. A systematic review on the relationship between sedentary behaviour and physical activity in adults also found a negative (inverse) association for total and domain-specific sedentary behaviours and physical activity (Mansoubi et al., 2014). In Mansoubi et al. (2014), the magnitude of the association was dependent on the type of physical activity: small to medium negative associations between sedentary behaviour and moderate-to-vigorous physical activity, and medium to large negative associations between sedentary behaviour and light-intensity physical activity. This could not be examined with university students due to the nature of our review (i.e., only the statistical significance, and not the strength of the association, was examined). Nevertheless, our findings seem to reinforce the idea that sedentary behaviour is displaced by physical activity (and vice versa). As such, promoting physical activity (especially light-intensity physical activity) may be a good way to reduce sedentary behaviour in university students.

Indeterminate associations were found between obesity markers and screen time (TV). The relationship between sedentary behaviour and obesity has been extensively studied in the literature. A recent review of reviews (Biddle et al., 2017) found either inconclusive or small associations between self-reported sedentary behaviour and adiposity in adults, with device-based sedentary behaviour yielding null associations. The authors concluded that 'evidence is generally not supportive of the association between sedentary behaviour and adiposity and obesity' (Biddle et al., 2017, p. 144). Given the inconsistency in the sedentary behaviour-obesity relationship found in our review, this conclusion may also apply to university students. Further research is needed to clarify if total or domain-specific sedentary behaviours are somehow associated with obesity in university students. Identifying which variables are consistently associated with obesity should be of concern to researchers, considering the high prevalence of overweight and obesity among university students from both developing and developed countries (Peltzer et al., 2014).

4.1. Directions and recommendations for future research

As found in previous reviews of sedentary behaviour in adults (e.g., Rhodes et al., 2012), the majority of correlates investigated were intrapersonal, with a limited number of studies having examined interpersonal, environmental, or time variables. In our review, only intrapersonal correlates were investigated frequently enough (four or more times) to determine associations with sedentary behaviour. This underscores the need for further research on potential correlates of sedentary behaviour that cover the full socio-ecological breadth (Sallis et al., 2008). In addition, a special focus on modifiable correlates is required to address the issue of reducing sedentary behaviour in university students. While non-modifiable correlates (e.g., socio-demographic) might be of interest to signal sub-population targets, design of future interventions should be informed by research on modifiable variables that have been consistently and sufficiently associated with sedentary behaviour. In this regard, intervention development also requires evidence on determinants (rather than correlates) of sedentary behaviour. Most of the studies in our review were cross-sectional; therefore, the evidence for true determinants remains elusive. Longitudinal and experimental studies would be necessary to examine whether these variables are in fact determinants causally related to sedentary behaviour.

In terms of sedentary behaviour measurement, there was a predominance of self-reports, with few studies relying on accelerometer-based measures. Self-reports tend to underestimate sedentary behaviour (Chastin et al., 2014), probably due to the difficulty to recall a behaviour highly prevalent and passive in nature. Accelerometer-based measures, however, are not exempt from flaws. Accelerometers have also been shown to underestimate sedentary behaviour (Kozey-Keadle et al., 2011) and should incorporate an inclinometer in order to differentiate sitting from standing (Byrom et al., 2016). In addition, unlike context specific self-reports, they do not provide contextual information on sedentary behaviour patterns. A combination of both self-reported and accelerometer-based measures is recommended when assessing domain-specific sedentary behaviours (Healy et al., 2011). Given that different sedentary behaviour domains may be influenced by different variables, assessing contextual information is essential in the study of correlates/determinants. Last, most self-reports in our review were non-validated. Even when validated, the majority were not specific to sedentary behaviour, hence information of the context and domain was not examined. The adoption of specific and validated measures in future research should offer a richer picture on sedentary behaviour patterns (i.e., contextual information), facilitate comparisons across studies, and reduce the risk of performance bias (the criterion with the highest risk of bias among the included studies).

In addition to performance bias, sampling methods and confounding have also been important sources of risk of bias among the included studies and deserve special attention in upcoming studies. Using probability sampling (e.g., random sampling, multistage sampling) and statistical methods to eliminate confounding effects (e.g., stratification, multivariate models) will help strengthen the available evidence. This is relevant as a majority of studies in our review were rated as high risk of bias and were therefore not included in the analysis of correlates. Improving the design of future studies as recommended should contribute to reduce the overall risk of bias and, in turn, facilitate the synthesis of all or most of the available evidence in systematic reviews.

Of note, many studies presented an unclear risk of attrition bias due to incomplete reporting, which poses an important obstacle in the assessment of risk of bias. Authors can reduce incomplete reporting by employing standardized reporting guidelines (e.g., STROBE statement for observational studies; Von Elm et al., 2007). In relation to reporting, sample description has likewise room for improvement. Key information such as university students' major subject of study or enrolment pattern were missing in most studies. These data are important in order to examine sub-group comparisons (e.g., online vs on-campus students, undergraduate vs postgraduate students).

4.2. Study limitations

Some limitations must be acknowledged for our review. First, only published literature was searched, potentially leading to an over representation of significant findings (publication bias). Second, the key

terms from our search strategy were searched only in abstract and title, which may have resulted in missing relevant studies. Few of the included studies were conducted specifically to analyse the relationship between potential correlates and sedentary behaviour, and thus it is possible that other similar studies were missed if associations between potential correlates and sedentary behaviour were explored but not included in the abstract. Last, following the methodology described by Sallis et al. (2000b), only the direction between sedentary behaviour and a given variable was coded, excluding its strength. Most of the debates in the area of sedentary behaviour concern the magnitude of the associations with other variables, however. For example, the association between screen time and body fatness has been shown to be significant but small in magnitude, which questions whether such small associations are practically meaningful (Biddle et al., 2017). Future reviewers need to reflect on whether extracting data with regard to the magnitude of the associations is meaningful and how to embed this additional information within current and commonly used methodologies for the study of correlates (e.g., Sallis et al., 2000b).

5. Conclusions

The evidence suggests that a large range of correlates of sedentary behaviour for university students has been studied, yet only three intrapersonal correlates were sufficiently investigated to determine an overall association: physical activity (negative association with sitting time), obesity markers (indeterminate associations with TV viewing), and gender - female (null associations with total sitting time and screen time). Further research on variables in the physical and interpersonal environments is needed. In addition, most correlates investigated were non-modifiable variables. Although these may assist in determining the sub-groups at risk of being sedentary, a greater focus on modifiable correlates is recommended in order to identify variables that can be targeted in behaviour change interventions. The majority of studies relied upon cross-sectional design, limiting causal inference. Employing more longitudinal or experimental designs will enable the identification of determinants. Last, over half of the studies were rated as high risk of bias and were not included in the analysis of correlates. Improvements in designing and reporting upcoming studies should contribute to strengthening the available evidence, which will benefit future reviewing efforts.

Disclosures

The overall findings of the systematic review were presented in form of poster presentation at the Exercise & Sports Science Australia (ESSA) conference in Brisbane, March 2018.

Conflict of interest statement

OC, JB, IV, and GB report no conflict of interest. SJHB received funding in 2016 for consultancy work for Halpern PR Limited. SJHB is an international advisory panel member for the ‘Get Britain Standing’ campaign.

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Appendix A. Supplementary data

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2.3 How the Publication Contributes to the Advancement of the Research Area

Study 1 featured a systematic review of the literature on the correlates of sedentary behaviour in university students using the socioecological framework (McLeroy et al., 1988). A total of 189 variables were examined as potential correlates of sedentary behaviour for university students. Following the specific threshold used in previous reviews (i.e., variables investigated in ≥4 studies; Sallis et al., 2000b) and after excluding high risk of bias studies, overall associations between three intrapersonal correlates and various sedentary behaviour domains could be established: physical activity, gender, and obesity markers (e.g., Body Mass Index, waist circumference). Of these, only physical activity presented consistent results, indicating a negative association between time spent in sedentary behaviour and physical activity (MET min/week). These findings reinforce the idea that promoting physical activity (especially light-intensity physical activity) may be a good way to reduce sedentary time in university students.

Moreover, this systematic review contributes to the field by providing guidance on the direction of future research. A large number of gaps in the literature were identified. For example, results underscored the need for further research on modifiable correlates of sedentary behaviour that cover all constructs within the socio-ecological framework. We consider that cognitive (e.g., attitude towards sedentary behaviour, perceived social norms towards sitting) and motivational factors (e.g., perceived health risks, sedentary behaviour habits) are particularly important in future research, as these are often targeted in behaviour change interventions (Rollo et al., 2016). In addition, the variables that were not included in the final analyses due to lack of sufficient studies could constitute the basis for future research on the correlates of sedentary behaviour, with the aim of trying to confirm associations that were so far identified in a small number of studies.

2.4 Study 2: How Sedentary are University Students? A Systematic Review and Meta-analysis

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How Sedentary Are University Students? A Systematic Review and Meta-Analysis

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Abstract
Accumulating high volumes of sedentary behaviour is a risk factor for multiple negative health-related outcomes. The objective of this review was to synthesise the evidence on the levels of sedentary behaviour in university students. Screened records from 13 databases were included if (i) published after 2007 and (ii) reported on university students' amount of total or domain-specific sedentary behaviour. Sub-group and meta-regression analyses were conducted to investigate potential sources of heterogeneity (moderators). A total of 125 studies met the inclusion criteria. Most studies were cross-sectional (84%) and reported screen time (61%) or total sedentary time (39%). Self-reported data indicated that university students spend 7.29 h per day being sedentary. The levels of total sedentary behaviour were significantly higher when measured with accelerometers ($M = 9.82$ h per day). Computer use presented significantly higher prevalence over other modalities of screen time. Among the explored factors (i.e. countries' income, age, gender, and study's publication date), only publication date significantly moderated sedentary behaviour. Results suggest that a considerable proportion of university students (i) engage in higher levels of sedentary time compared to the general young adult population and (ii) accumulate levels of sedentary time that have been associated with an increased risk for detrimental health outcomes. In addition, meta-regression analyses suggest that sedentary time has increased over the last 10-year period among university students. These findings may inform future initiatives and policies targeting university students' sedentary behaviour. Further research is needed to identify the factors moderating sedentary behaviour in the university setting.

Keywords Sitting · Sedentary time · College students · Correlates

Introduction

Sedentary behaviours are waking activities characterised by low energy expenditure and undertaken in a sitting or reclining posture, e.g. reading, watching television, or driving (Tremblay et al. 2017). Recently, engaging in high volumes of sedentary behaviour has been recognised as a risk factor for premature death and several chronic diseases, e.g. type 2 diabetes, metabolic syndrome, and cardiovascular disease (Patterson et al. 2018; Biswas et al. 2015; Wilmot et al. 2012). Evidence also suggests that high levels of sedentary behaviour might have an impact on mental well-being, including an increased risk of anxiety and depression (Teychenne et al. 2015; Zhai et al. 2015). Of note, the health risks of sedentary behaviour have been shown to be somewhat independent of meeting current physical activity guidelines (Thorp

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et al. 2011; Dogra and Stathokostas 2012). While physical activity can play a protective role as a counter to the negative effects of time spent sedentary, levels of physical activity that are considerably higher than currently recommended guidelines may be needed to eliminate the mortality risk associated with sedentary behaviour (Ekelund et al. 2016).

Accelerometer-based estimates show that adults in high-income countries spend a significant proportion of time being sedentary, ~ 55% to 65% of their waking hours (Hansen et al. 2012; Matthews et al. 2008). Moreover, there is evidence suggesting that time spent in sedentary behaviour is increasing (Du et al. 2019). Studies highlight substantial variation in sedentary time according to socio-demographic factors, such as age, gender, or economic status (Lakerveld et al. 2017). 'Current occupation' has been identified as one of the key moderators (Loyen et al. 2016). For example, research consistently shows that white-collar workers report higher levels of sedentary behaviour when compared to the general population (Owen et al. 2011). This might explain why the majority of sedentary behaviour and public health research among working-aged adults concentrates on desk-based office workers (Gardner et al. 2016). Much like office workers, university students are also a population sub-group at risk of accumulating high levels of sedentary behaviour; activities such as attending lectures or studying likely involve long periods of sitting (Cotten and Prapavessis 2016). A cross-sectional study conducted in Brazil concluded university students spend an average of 8.3 h of self-reported sedentary time per day (Mussi et al. 2017), and the average is commonly two to three hours higher when using accelerometers (Clark et al. 2016; Conroy et al. 2013). Evidence thus exists suggesting that university students are highly sedentary (Rouse and Biddle 2010; Farinola and Bazán 2011) and that their sedentary behaviour levels are comparable to or likely to exceed those of desk-based office workers (Moulin and Irwin 2017). However, to our knowledge, the literature on sedentary behaviour levels in university students is yet to be reviewed systematically. University students are an important proportion of the young adult population, over 35% in most developed countries (Dragoescu 2013; Universities UK 2017). Gaining a better understanding of university students' volume and type of sedentary behaviours could inform future intervention and policy development for this potentially 'at-risk' population sub-group. Moreover, since many adult health-related behaviours are established during late adolescence and young adulthood, the university years are an important period for the development of future life patterns (US Department of Health and Human Services 2000).

The objective of the present study was to synthesise the available evidence regarding the amount of sedentary behaviour accumulated by university students. In particular, the purpose of this review was to (i) provide an overview of the existing studies that assessed sedentary behaviour in the university setting, (ii) describe the reported levels of total and domain-specific sedentary behaviour, and (iii) explore potential variation in sedentary behaviour levels according to a country's income, age, gender, and study's publication date.

Methods

The research protocol of this study was registered with the PROSPERO international prospective register of systematic reviews in October 2017 (registration number: CRD42017074198). The Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement and the Meta-analysis of Observational Studies in Epidemiology (MOOSE) guidelines were followed for the conduct and reporting of this review (Moher et al. 2009; Stroup et al. 2000). A completed PRISMA checklist is available as online supplementary material (File 1).

Search Strategy

A computerised search for literature was performed within the following databases: Web of Science (including Web of Science Core Collection and MEDLINE), SciELO, Scopus, and EBSCOhost MegaFile Ultimate (including CINAHL with Full Text, Academic Search Ultimate, PsycINFO, PsycARTICLES, Education Research Complete, Psychology and Behavioral Sciences Collection, ERIC, and SPORTDiscus with Full Text). Automatic search alerts were set up and maintained until the final analyses (November 2018) to identify new published papers since the original database search. The search strategy was developed with the assistance of a research librarian and included key words in three categories: 'student', 'university' (e.g. higher education, undergraduate), and 'sedentary behaviour' (e.g. sitting, screen time). The full search strategy for EBSCOhost MegaFile Ultimate is available as online supplementary material (File 2). In addition to the electronic search, reference lists of included studies were hand-searched to identify studies.

Inclusion Criteria

Studies that met the following criteria were included in the review: (1) published after Jan. 1, 2007, in a peer-reviewed journal in English, Spanish, or French; (2) included university students (undergraduate or postgraduate students); and (3) reported on the students' levels of total and/or domain-specific sedentary behaviour. Study designs eligible for inclusion were observational (e.g. cross-sectional and prospective) and interventional (e.g. randomised controlled and quasi-experimental). For intervention studies, only baseline or control data were included. The starting point of the search (i.e. 2007) was chosen in order to capture the relatively current levels of

sedentary behaviour. For the type of sedentary behaviour, one or more of the following were included: total accelerometer-based sedentary time (with ≤ 100 activity counts assumed to be sedentary), total self-reported sedentary time (with total sitting time used as a proxy measure of total sedentary time in most self-report methods), screen time (e.g. TV viewing, computer use), occupational sedentary behaviour (e.g. lecture attendance, private study time), or passive transportation. Sedentary behaviour was reported either as a summary point estimate (e.g. mean minutes/hours per day) or as a proportion (e.g. percentage of the sample sitting more than 6 h per day).

Selection Process

Two reviewers (OC and GB) independently screened the title/abstract of articles identified through database or manual searches to assess whether they met the inclusion criteria. Full-text papers of retained articles were then retrieved and examined by the same two reviewers independently, with any discrepancies resolved with a consensus discussion (89% agreement prior to discussion). Disagreements that could not be resolved by consensus were discussed with a third reviewer (SJHB).

Data Extraction

The same two reviewers (OC and GB) independently extracted data on publication details, study design, sample characteristics, measurement of sedentary behaviour, type of sedentary behaviour, level of measurement (e.g. average minutes per day, threshold), and reported amount of sedentary behaviour. The reviewers utilised a standardised pre-piloted data extraction form and resolved any discrepancies with discussion and consensus (84% agreement prior to discussion). Where consensus could not be reached, a third reviewer (SJHB) was consulted.

Data Analysis

Studies reporting sedentary behaviour as mean (standard deviation) and/or proportion (e.g. percentage of the sample sitting more than 6 h per day) were inputted in the software Comprehensive Meta-analysis version 3 (CMA; Biostat Inc., Englewood, USA) for quantitative synthesis. When sedentary behaviour was reported as median (interquartile range) or data were missing (e.g. standard deviation), corresponding authors were contacted by email for additional information. After seven business days, a second reminder was sent if there was no response to the initial email. Of the 20 authors contacted, 12 authors provided the requested data. Two authors could not comply with the request due to no current access to the data. The remaining six authors did not reply to either of the two emails that were sent.

Confidence intervals (95%) were calculated for every sedentary behaviour point estimate and proportion. The variability in the point estimates and proportions between the included studies was measured with the Q and L^2 statistics. A significant Q-test and a high L^2 value (above 75%) are considered indicators of substantial heterogeneity (Higgins and Green 2011). Sub-group (categorical) and meta-regression analyses were conducted to investigate the contribution of specific variables to heterogeneity. Sub-group analyses were employed for a particular sedentary behaviour domain when more than four articles were available for each sub-group variable (Fu et al. 2011). Based on this criterion, three categorical variables were included in the sub-group analyses: countries' income status (e.g. middle-income vs high-income), screen time modality (e.g. TV viewing vs computer use), and assessment method (self-reported vs accelerometer-based measures). Meta-regressions were employed when ten or more studies were available for a particular sedentary behaviour domain (Higgins and Green 2011). This criterion resulted in the inclusion of three continuous variables in the meta-regression: mean sample age, study's publication date, and percentage of females in the sample. All analyses were conducted under a random-effects model, owing to the methodological assumption that included studies reflect different populations.

A common scale (hours per day) was chosen in order to facilitate comparison across studies, transforming the raw data where necessary (see online materials for study-specific details). When studies with repeated measures were included into the meta-analysis ($k = 8$), only the first point estimate or proportion (T1) was computed in CMA in order not to over-represent prospective cohort studies. Similarly, when studies reported data separately for weekdays and weekend ($k = 14$), only the weekdays point estimate or proportion was meta-analysed (tables with data broken down by time frame are available as online supplementary material—Files 3 and 4). Data reported as categories ($k = 27$ studies) were transformed into proportions for different cut-off criteria (e.g. screen time—TV: 36.9% of participants < 1 h/day/38% 1–2 h/day/25.1% > 2 h/day was transformed into 63.1% of participants > 1 h/day/25.1% > 2 h/day). When sedentary behaviour was reported separately by gender or treatment group (i.e. multiple sub-groups within a study; $k = 14$ studies), the sub-groups were combined for each study following previous guidelines (Borenstein et al. 2009; formula available as online supplementary material—File 5). As such, the summary data for each sub-group (mean, standard deviation, and sample size) were used to recreate the sedentary behaviour point estimate for the study as a whole, allowing a wider comparison across studies (i.e. study as the unit of analysis).

Risk of Bias

The risk of bias was assessed using a version of the Cochrane Collaboration's Tool for Assessing Risk of Bias (Higgins et al.

2011) adapted for observational studies (Poitras et al. 2016; Prince et al. 2017). Studies were assessed for potential biases, including selection bias (random sampling method), performance bias (sedentary behaviour measurement), attrition bias (completeness of outcome data), and selective reporting bias (selective outcome reporting). Each potential source of bias was marked as high, low, or unclear risk of bias according to pre-specified criteria. Risk of bias assessments were carried out by two reviewers independently (OC and GB). Discrepancies were identified and resolved through discussion (83% agreement prior to discussion), with a third reviewer mediating where necessary (SJHB). For each study, a composite risk of bias score was calculated by summing the number of criteria marked 'low risk of bias' (50% criterion). Subgroup analyses (high risk of bias studies vs low risk of bias studies) and meta-regressions (number of criteria marked 'low risk of bias') were conducted to explore whether risk of bias results explained variation in the sedentary behaviour point estimates (sensitivity analysis). The risk of bias instrument is available as online supplementary material (File 6). In addition, a further sensitivity analysis was conducted with the studies' sample size as a meta-regression (moderator) variable, in order to explore potential variation of results according to the number of participants included.

Results

Narrative Synthesis ($k = 125$)

Description of Studies

A total of 125 studies met the inclusion criteria (see Fig. 1 for PRISMA flowchart). Studies were published in English (88%) or Spanish (12%) and included data from 110,214 participants, with a median sample size of 306 participants (IQR = 149–751). Most studies were cross-sectional (84%), with smaller proportions being prospective cohort studies (10%) and randomised control trials (6%). Studies were conducted in Europe (32%), Asia (23%), North America (21%), South America (11%), Africa (9%), and Australia (2%). Over half of the participants were described as undergraduate students (61%). However, data on the students' enrolment status was missing in one third of the studies (33%). A comprehensive overview of all included studies per sedentary behaviour domain is available as online supplementary material (Files 7, 8, 9, 10, 11), along with the full list of citations (File 12).

Measurement of Sedentary Behaviours

Most studies (93%) based their measurements on self-reported sedentary behaviour (e.g. questionnaires or inventories). The primary measure of sedentary behaviour was screen time (61%), followed by total sedentary behaviour (39%), occupational sedentary behaviour (10%), and passive transportation (2%). Sedentary behaviour was reported both as a point estimate (73%) and as a proportion (33%). Only three studies reported data on breaks from sedentary behaviour (e.g. frequency and duration of movement breaks).

Risk of Bias Assessment

The majority of studies were classified as low risk of bias studies (68%), according to the composite risk of bias score. In relation to the risk of bias per bias criterion, over half of the studies (57%) measured sedentary behaviour employing a non-validated tool and were thus coded as having a high risk of performance bias. Similarly, a majority of studies (61%) had a high risk of selection bias due to the use of convenience (non-random) samples. Only a few studies (16%) presented high attrition bias. Finally, studies were predominantly free of selective reporting bias (81%). Detailed risk of bias results are available as online supplementary material (File 13).

Quantitative Synthesis ($k = 119$)

Total Sedentary Behaviour

Self-reported Sedentary Time For self-reported sedentary time, 32 studies reported point estimates (Table 1). In addition, six studies reported proportions (Table 2). Sufficient studies reported on point estimates of sedentary time to allow for the conduct of heterogeneity analyses specifically for this sedentary behaviour domain (i.e. ≥ 10 studies for meta-regression and ≥ 4 studies for each sub-group variable). Heterogeneity was significant and high ($Q = 6566.23$, $df = 31$, $p = 0.00$, $L^2 = 99.52\%$). The difference in self-reported sedentary time between upper middle-income and high-income countries was not statistically significant (upper middle-income: 7.84 h/day, 95% CI: 6.92–8.76, $k = 19$; high-income: 6.87 h/day, 95% CI: 6.24–7.49, $k = 11$; $Q = 2.93$, $p = 0.08$). The difference in self-reported sedentary time between high risk of bias and low risk of bias studies was also non-significant (high risk of bias: 7.76 h/day, 95% CI: 7.06–8.47, $k = 5$; low risk of bias: 7.21 h/day, 95% CI: 6.57–7.84, $k = 27$; $Q = 1.33$, $p = 0.24$). The study's publication date significantly moderated self-reported sedentary time, with recent studies reporting higher point estimates (Table 3).

Accelerometer-Based Sedentary Time For accelerometer-based sedentary time, eight studies reported point estimates (Table 1). This number was sufficient to compare self-reported and accelerometer-based sedentary time. The summary point estimate for accelerometer-based sedentary time (9.82 h/day, 95% CI: 8.63–11.01, $k = 6$) was significantly

higher than the one for self-reported sedentary time (7.29 h/day, 95% CI: 6.73–7.85, $k = 32$; $Q = 14.22$, $p = 0.00$).

Domain-Specific Sedentary Behaviour

Screen Time For screen time (including TV, computer, mobile phone, video games, or a combination of these), 37 studies reported point estimates (Table 1). In addition, 41 studies reported proportions (Table 2). Sufficient studies reported on TV viewing, computer use, and the proportion of university students exceeding two hours of daily TV viewing to allow for the conduct of heterogeneity analyses specifically for these domains.

For the TV viewing point estimate, heterogeneity was significant and high ($Q = 9345.46$, $df = 20$, $p = 0.00$; $L^2 = 99.78\%$). The difference in TV viewing between high risk of bias and low risk of bias studies was non-significant (high risk of bias: 1.62 h/day, 95% CI: 1.38–1.87, $k = 9$; low risk of bias: 1.38 h/day, 95% CI: 0.94–1.82, $k = 12$; $Q = 0.91$, $p = 0.33$). None of the examined variables significantly moderated the levels of TV viewing (Table 3).

For the proportion of university students exceeding two hours of daily TV viewing, heterogeneity was significant and high ($Q = 2750.24$, $df = 14$, $p = 0.00$; $L^2 = 99.49\%$). The difference in the proportion of students exceeding the two hours cut-off between high risk of bias and low risk of bias studies was non-significant (high risk of bias: 42% exceeding the cut-off, 95% CI: 27–58, $k = 8$; low risk of bias: 27% exceeding the cut-off, 95% CI: 16–40, $k = 7$; $Q = 2.22$, $p = 0.13$). None of the examined variables significantly moderated the proportion of university students exceeding two hours of daily TV viewing (Table 3).

For the computer use point estimate, heterogeneity was significant and high ($Q = 3727.7$, $df = 15$, $p = 0.00$; $L^2 = 99.59\%$). There was no significant difference in computer use between university students from lower middle-income and high-income countries (lower middle-income countries: 2.21 h/day, 95% CI: 0.98–3.45, $k = 4$; high-income countries: 3.05 h/day, 95% CI: 2.25–3.85, $k = 10$; $Q = 1.24$, $p = 0.26$). The difference in computer use between high risk of bias and low risk of bias studies was non-significant (high risk of bias: 3.26 h/day, 95% CI: 2.71–3.82, $k = 6$; low risk of bias: 2.7 h/day, 95% CI: 1.97–3.42, $k = 10$; $Q = 1.46$, $p = 0.22$). None of the examined variables significantly moderated the levels of computer use (Table 3).

A sufficient number of studies were available to compare the time spent in different screen time modalities. University students reported significantly more time using the computer (2.91 h/day, 95% CI: 2.32–3.5, $k = 16$) than watching TV (1.49 h/day, 95% CI: 1.22–1.76, $k = 21$; $Q = 18.16$, $p = 0.00$) or playing video games (0.37 h/day, 95% CI: 0.11–0.62, $k = 7$; $Q = 59.47$, $p = 0.00$).

Occupational Sedentary Behaviour For occupational sedentary behaviour (including time spent studying, in lectures, or a combination of these), nine studies reported point estimates (Table 1). In addition, four studies reported proportions (Table 2). There were not sufficient studies to allow for the conduct of heterogeneity analyses specifically for this sedentary behaviour domain.

Occupational Sedentary Behaviour A total of two studies reported passive transportation using point estimates (Table 1). There were not sufficient studies to allow for the conduct of heterogeneity analyses specifically for this sedentary behaviour domain.

Discussion

To our knowledge, the present systematic review and meta-analysis is the first to examine the amount of total and domain-specific sedentary behaviour accumulated by university students. Regarding total sedentary behaviour, self-reported estimates across 32 studies indicate that university students spend on average 7.29 h per day sitting. The Eurobarometer 64.3 investigated the levels of self-reported sedentary time across multiple countries and reported that adults aged 18–25 spend on average 5.86 h per day sitting (95% CI: 5.76–5.96, $n = 3114$; European commission 2012). Therefore, our data might be an indication that most university students engage in higher levels of self-reported sedentary time compared to the general young adult population (in high-income countries). This also seems to be the case when accelerometer-based measures of sedentary behaviour are employed. Findings from the US National Health and Nutrition Examination Survey (NHANES) indicate that adults aged 20–29 spend on average 7.48 h per day being sedentary (95% CI: 7.26–7.69, $n = 636$; Matthews et al. 2008). Our data across six studies suggest that many university students engage in larger volumes of sedentary behaviour per day ($M = 9.82$ h/day, 95% CI: 8.63–11.01). While further research is needed to examine the extent and causes of this apparent discrepancy, the high levels of sedentary behaviour in university students might be explained by the activities that they usually perform, requiring long periods of sitting (e.g. studying, writing assignments, attending lectures).

Increasing our knowledge of the patterns and distributions of sedentary behaviour in university students is relevant given that the quantity of time spent sedentary has been recognised as a risk factor for several negative health-related outcomes (Biswas et al. 2015; Wilmot et al. 2012; Zhai et al. 2015). Previous meta-analyses have investigated the dose–response

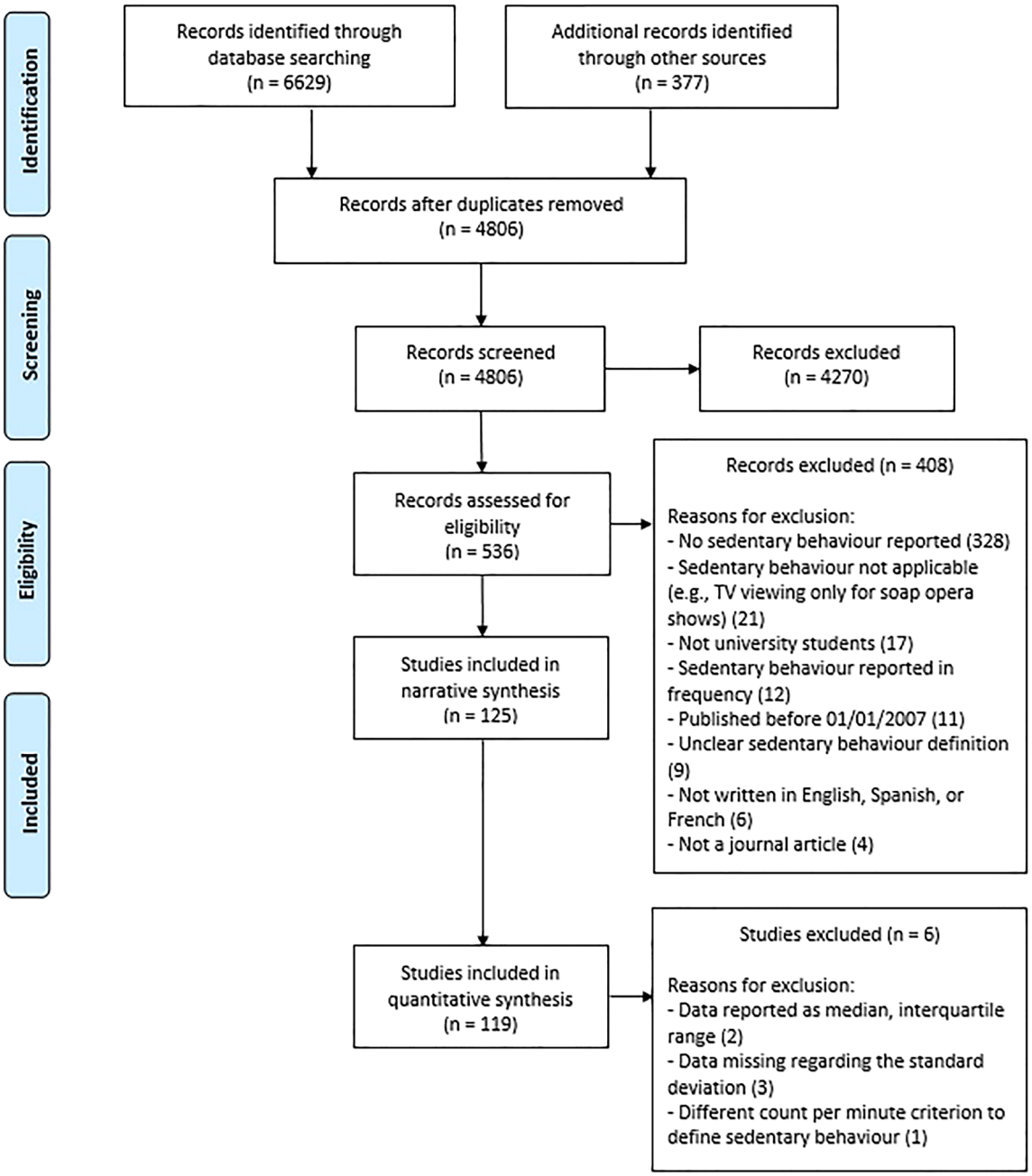

Fig. 1 Flow chart for the articles included in the systematic review and meta-analysis

relationship between self-reported sitting time and mortality risk, after controlling for physical activity. Patterson et al. (2018) found positive and non-linear associations between self-reported sitting and cardiometabolic/mortality outcomes across 34 studies ($n = 1{,}331{,}468$). A threshold of between 6 and 8 h per day of total sitting was identified, above which the mortality risk is increased. Chau et al. (2013) reported similar results: the hazard ratios for all-cause and cardiovascular mortality start to increase significantly from 7 to 8 h of self-reported sitting per day onwards ($n = 595{,}086$). In relation to accelerometer-based sedentary behaviour, a recent meta-analysis has also found evidence of a non-linear association between time spent sedentary and risk of death across eight studies ($n = 36{,}383$). Authors reported a statistically significant higher mortality risk for daily sedentary times of 9.5 or more hours (Ekelund et al. 2019). Given that our summary point estimates for total self-reported and accelerometer-based sedentary time are within or slightly above the mentioned thresholds, we interpret that a considerable percentage of students are likely to be at an increased risk for the negative health consequences of sitting. The summary proportions for self-reported sedentary time also reinforce this idea. Around

Table 1 Time spent in sedentary behaviour among university students

Sedentary behaviour domain[a]	No. of studies[b]	No. of participants	Mean (h/day), 95% CI
Total sedentary behaviour			
Sedentary time	32	23,757	7.29 (6.73–7.85)
Device-based sedentary time (accelerometer)	6	781	9.82 (8.63–11)
Device-based sedentary time (accelerometer—ActivPAL)	2	157	10.7 (10.4–10.96)
Domain-specific sedentary behaviour			
Screen time (TV)	21	14,589	1.49 (1.22–1.76)
Screen time (computer)	16	8333	2.91 (2.32–3.5)
Device-based screen time (computer)	1	9	8.04 (6.49–9.59)
Screen time (video games)	7	2841	0.37 (0.11–0.62)
Screen time (mobile phone)	3	2198	3.74 (1.25–6.24)
Screen time (TV + computer + video games)	3	1823	2.26 (2.11–2.4)
Screen time (TV + computer)	1	94	6.2 (5.49–6.9)
Screen time (computer + video games)	1	2209	2.04 (1.96–2.11)
Occupational sedentary behaviour (study time)	7	2194	2.85 (2.19–3.51)
Occupational sedentary behaviour (time in class)	1	82	2.23 (2.01–2.44)
Occupational sedentary behaviour (study time + time in class)	1	1026	5.24 (5.1–5.37)
Passive transportation	2	473	1.05 (0.67–1.43)

[a] Sedentary behaviour assessed by self-report, unless specified (i.e. device-based). For accelerometer-based sedentary time, the count per minute was ≤ 100. Data from the thigh-worn ActivPAL are presented separately as it differs from other accelerometers by using both static acceleration and inclination to interpret postures

[b] Some studies report point estimates for more than one sedentary behaviour domain. Thus, total table numbers do not match with the total number of studies reporting point estimates

one third of the university students reported spending more than 8 h sitting per day, in two studies totalling 6923 participants. Taken together, these findings might be relevant to inform the development and implementation of public health programmes targeting sitting time reductions in university students, along with physical activity promotion. Sedentary behaviour reduction and other behaviour change interventions with adolescents and young adults offer the opportunity to promote a lifelong healthy lifestyle (US Department of Health and Human Services 2000). This is important as university students are more likely to work in white-collar occupations upon graduation and will thus be potentially exposed to high levels of sitting during workdays. In addition, meta-regression analyses with self-reported total sedentary behaviour suggest that time spent sedentary has increased over the last 10-year period. This finding is consistent with previous studies; Du et al. (2019) noted that self-reported sedentary time among US adults has increased in the last decade across all analysed sub-groups (including age, gender, educational level, race/ethnicity, and BMI categories). While the reasons for this positive trend remain unclear and warrant further investigation, it is plausible that recent environmental and social changes prompt individuals to sit down for longer periods (e.g., wider availability of screen-based devices and passive forms of transportation, increased number of sedentary, office-based occupations).

Over half of the included studies reported on university students' screen time. Several studies have reported significant associations between different forms of screen time (mainly TV) and negative health-related outcomes in young adults. This includes physical effects, e.g. poor sleep quality (Wu et al. 2015), increased risk of headaches (Montagni et al. 2016), chronic neck pain (Camacho and Nakazato 2018), and psychological effects, e.g. increased risk of depression (Madhav et al. 2017) and decreased well-being (Kross et al. 2013). Alternatively, recent calls have been made claiming that the use of screens may also have positive effects (Bell et al. 2015; Gao et al. 2015) and that certain modalities of screen time may be more detrimental than others (Altenburg et al. 2013). Rather than the total amount of screen time, the purpose of screen use might be more important (e.g. recreational vs educational screen time). Unfortunately, the purpose of screen use was rarely reported among the included studies, and therefore warrants further attention. In our review, the dominant screen time modality used by university students was the computer. These data may suggest that future epidemiology studies on screen time in university students, or intervention studies targeting screen time reduction, should pay closer attention to computer use.

A substantial variation in the sedentary behaviour point estimates and proportions was found across the included

Table 2 Prevalence of university students exceeding daily cut-offs for various sedentary behaviour domains

Sedentary behaviour domain[a]	% of university students exceeding the cut-off (95% CI) (no. of studies[b]; no. of participants)						
	15 min	30 min	45 min	1 h	2 h	3 h	4 h
Total sedentary behaviour							
Sedentary time						82.5 (75.7–87.6) (1; 154)	82.7 (75.7–88.2) (1; 140)
Domain-specific sedentary behaviour							
Screen time (TV)				70.8 (63.6–77) (9; 13,355)	34.8 (26.1–44.7) (15; 31,002)	26.7 (17.3–38.8) (3; 1433)	34.5 (14.2–62.6) (3; 1341)
Screen time (computer)				75.3 (52.2–89.5) (4; 4120)	39.7 (29.1–51.5) (7; 4795)	44.2 (42.3–46.2) (1; 2511)	14.4 (11.5–17.7) (1; 500)
Screen time (video games)	78.7 (75.3–81.7) (1; 630)		33.1 (29.6–36.9) (1; 630)	53.3 (21.9–82.2) (4; 1672)	17.6 (9.6–30.3) (5; 18,211)	7.4 (1.6–27.6) (3; 959)	15.4 (10.6–21.7) (1; 162)
Screen time (mobile phone)				62 (57.4–66.4) (1; 443)	66.9 (15.1–95.8) (2; 1085)	63.8 (55.3–71.6) (1; 130)	28.5 (23.7–33.9) (1; 301)
Screen time (TV + computer + video games)				79 (75.4–82.2) (1; 553)	72.9 (53.2–86.4) (4; 2574)		
Screen time (TV + computer)				41.8 (36.7–47) (1; 354)		42.9 (36.6–49.5) (1; 221)	16.5 (14.9–18.2) (1; 1976)
Screen time (TV + video games)				56 (49–62.7) (1; 200)	57.7 (19.5–88.4) (2; 3406)		
Occupational sedentary behaviour (study time)		59.3 (51.3–66.8) (1; 150)		66.6 (65–68.1) (1; 3384)	43.2 (41.5–44.8) (1; 3384)	18.1 (13.5–23.7) (1; 221)	

Sedentary behaviour domain[a]	% of university students exceeding the cut-off (95% CI) (no. of studies[b]; no. of participants)					
	4.5 h	5 h	6 h	8 h	10 h	16 h
Total sedentary behaviour						
Sedentary time			49.1 (41.2–56.9) (4; 3551)	31 (30.4–32.6) (2; 6923)		
Domain-specific sedentary behaviour						
Screen time (TV)			2.8 (1.9–4.3) (2; 1025)			
Screen time (computer)		4 (1.7–9) (1; 125)			1.3 (0.6–2.4) (1; 694)	
Screen time (video games)		4.8 (2.4–9.4) (3; 972)				
Screen time (mobile phone)	27.6 (20.7–35.9) 1; 130)	55.4 (51.1–59.7) (1; 503)	10.7 (6.5–17.2) (1; 130)			1.6 (0.7–3.8) (1; 301)
Screen time (TV + computer + video games)			41.4 (38.5–44.4) (1; 1058)			
Screen time (TV + computer)						
Screen time (TV + video games)						
Occupational sedentary behaviour (study time)						

[a] All sedentary behaviour domains were assessed by self-reports

[b] Some studies report proportions for more than one sedentary behaviour domain. Thus, total table numbers do not match with the total number of studies reporting proportions

Table 3 Meta-regressions of moderators for sedentary behaviour in university students

Moderator	No. of studies	β	95% CI	p	R-square
Self-reported sedentary time					
Publication date	32	0.2	0.01 to 0.40	0.03	0.00
Percentage of females	31	0.00	− 0.03 to 0.03	0.91	0.03
Mean sample age	24	− 0.07	− 0.29 to 0.14	0.51	0.00
Sample size	32	− 0.00	− 0.00 to 0.00	0.83	0.00
No. of low risk of bias criteria	24	− 0.19	− 1.09 to 0.71	0.67	0.00
Screen time (TV)					
Publication date	21	0.00	− 0.10 to 0.11	0.94	0.01
Percentage of females	19	0.00	− 0.02 to 0.03	0.74	0.00
Mean sample age	14	0.16	− 0.00 to 0.32	0.06	0.21
Sample size	21	0.00	− 0.00 to 0.00	0.08	0.38
No. of low risk of bias criteria	21	− 0.33	− 0.75 to 0.08	0.11	0.00
Screen time (TV—% > 2 h)					
Publication date	15	0.13	− 0.04 to 0.3	0.14	0.00
Percentage of females	15	− 0.01	− 0.03 to 0.01	0.36	0.00
Sample size	15	0.00	− 0.00 to 0.00	0.41	0.08
No. of low risk of bias criteria	15	− 0.34	− 0.85 to 0.16	0.18	0.00
Screen time (computer)					
Publication date	16	− 0.15	− 0.36 to 0.04	0.13	0.00
Percentage of females	13	− 0.03	− 0.08 to 0.01	0.21	0.06
Mean sample age	11	0.3	− 0.27 to 0.88	0.3	0.00
Sample size	16	0.00	− 0.00 to 0.00	0.96	0.00
No. of low risk of bias criteria	16	− 0.46	− 1.1 to 0.18	0.16	0.26

studies. Given that studies used similar research designs, measurement tools, and modes of administration, we consider that heterogeneity might reflect differences across the included participants (and not methodological differences across the studies). We used sub-group and meta-regression analyses in order to investigate the contribution of specific factors to heterogeneity (i.e. countries' income, age, study's publication date, and gender). However, while these factors have contributed to variation in total or domain-specific sedentary behaviour in previous studies, only publication date was a significant moderator in our review. It might be that the factors explaining variation in university students are different from those in the general population. University-specific factors such as major subject of study, enrolment status, or year of enrolment are potentially relevant to explain variation in sedentary behaviour levels. For example, we can expect graduate students to have a higher workload than undergraduate students, thus accumulating more sitting hours. Similarly, full-time students might engage in higher levels of sitting than part-time students. That is, the found variability across the included studies might reflect different sedentary behaviour levels within the university student population. Unfortunately, these university-specific variables could not be analysed in our review due to lack of sufficient studies and poor study reporting. This constitutes a limitation for our meta-analysis, as it could have been more appropriate to calculate different summary point estimates and proportions for different groups of university students. Given the high heterogeneity, our summary data should be understood as an estimation of how sedentary are university students. Further research is needed exploring the factors influencing sedentary behaviour in the university setting.

Recommendations for Future Research

While the overall risk of bias was low for the majority of studies included in the systematic review, there were still two risk of bias criteria that deserve attention in upcoming studies: selection bias (marked as high risk of bias in 61% of the studies) and performance bias (marked as high risk of bias in 57% of the studies). To reduce these risks, future studies should use probability samples and validated measurement tools. Second, only three studies reported data on breaks from sedentary behaviour (e.g. frequency and duration of movement breaks). Along with reducing overall sitting time, breaking up sitting time frequently is recommended by several national public health guidelines (Australian Department of Health 2014; UK Department of Health 2011). Therefore, the frequency and duration of movement breaks need to be assessed and reported. Third, we found that the summary

point estimate for accelerometer-based sedentary time was significantly higher than the one for self-reported sedentary time. This is consistent with previous literature suggesting that self-reports underestimate sedentary behaviour when compared to accelerometer-based methods (Chastin et al. 2014). However, accelerometers do not provide contextual information and this information may be crucial to better understand sedentary behaviour patterns and inform future interventions. We recommend a combination of both accelerometer-based and self-reported measures in future epidemiology studies. Last, sample description should be improved; relevant information such as university students' enrolment status or major subject of study was missing in most studies. This is important information for future reviewing efforts, as well as to potentially identify sub-groups of students at risk of being highly sedentary and inform intervention development.

Study Limitations and Strengths

Searches were restricted to published studies due to time constraints, which may have resulted in missing relevant literature. Similarly, we only searched for key terms in the abstract and title and, thus, it is possible that potentially eligible articles were not identified. For example, the majority of studies assessed self-reported sitting with the International Physical Activity Questionnaire (IPAQ), which is a questionnaire focused on physical activity. Other study authors using the IPAQ may have prioritised the physical activity findings, not including sedentary behaviour-related terms in the article's title and abstract. However, a particular strength of our search strategy is that we reviewed articles in different languages (English, Spanish, and French) from a large number of electronic databases and reference lists of included articles. In addition, the PRISMA guidelines regarding the conduct and reporting of systematic reviews were carefully followed. Two researchers independently carried out the different stages of the review process (screening, data extraction, risk of bias assessment), reducing the risk of errors and maximising reliability.

Conclusions

Our findings suggest that most university students engage in high levels of sedentary behaviour, compared to different estimates from the general young adult population. In addition, a substantial proportion of university students seem to accumulate daily volumes of sedentary time that previous meta-analyses have associated with an increased risk for negative health outcomes. Moreover, meta-regression analyses suggest that time spent sedentary has increased over the last decade among university students. These findings may inform future health programmes and policies targeting sitting time reductions in university students. In terms of screen time, university students reported spending significantly more time using the computer than watching TV or playing video games. Last, while heterogeneity in the levels of sedentary behaviour was high, only one of the explored factors was a significant moderator (i.e. study's publication date). Further research is needed exploring the factors influencing sedentary behaviour in the university setting.

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Author Contributions OC, JB, IV, and SJHB contributed to the conception and design of the study, as well as to the development of the search strategy. OC and GB conducted the selection and data extraction processes, with input from SJHB. OC performed the data analysis and JB, IV, and SJHB assisted with the interpretation of findings. OC developed the first draft of the paper. All authors contributed to the drafting and revision of the final article. All authors approved the final submitted version of the manuscript.

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Compliance with Ethical Standards

Conflict of Interest OC, JB, IV, and GB report no conflict of interest. SJHB is an international advisory panel member for the 'Get Britain Standing' campaign.

Ethical Approval and Informed Consent Not applicable due to the nature of the manuscript (i.e. systematic review and meta-analysis).

Data-Sharing Statement All data relevant to the study are included in the article or uploaded as supplementary online information.

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2.5 How the Publication Contributes to the Advancement of the Research Area

To our knowledge, our systematic review and meta-analysis was the first to describe the published literature on the levels of sedentary behaviour in university students. This is relevant to public health given that the quantity of time spent sedentary is a risk factor for multiple negative health-related outcomes, including all-cause mortality, cancer, diabetes, and depression (Cong et al., 2014; Ekelund et al., 2019; Greer et al., 2015; Rebar et al., 2014; Teychenne, et al., 2015). Data from our review suggested that most university students (i) engage in higher levels of sitting compared to the general adult population, and (ii) accumulate daily volumes of sitting that have been associated with an increased risk for negative health-related outcomes. Based on the findings, we discussed implications for intervention and policy development in the university setting.

A substantial variation in the sedentary behaviour outcomes was found across the included studies. To address this, we used sub-group and meta-regression analyses to investigate the contribution of specific factors to heterogeneity. However, only the publication date was a significant moderator in our review. Therefore, as with Study 1, a key recommendation for future research was to investigate the factors influencing sedentary behaviour in the university setting, with a special focus on university-specific, modifiable factors to guide behaviour change efforts.

In addition, it is worth noting that most of the studies included in the review provided a self-reported measure of sedentary behaviour. Self-reports tend to underestimate sedentary behaviour, probably due to the difficulty of recalling a very prevalent (and mostly automatic) behaviour such as sitting (Chastin et al., 2014). We recommend the use of device-based measures in future research. Moreover, only two out of the eight studies reporting device-based sedentary behaviour used an accelerometer with an in-built inclinometer. The rest of studies relied in arm- or hip-mounted accelerometers, which infer sedentary behaviour from lack of movement. This measurement approach might be misleading as all non-stationary activities (including standing) are categorised as sedentary behaviour, regardless of whether they are performed in an upright or seated position (Kim et al., 2015). Future epidemiological studies in university students will provide more reliable estimates of sedentary behaviour by using thigh-mounted devices which directly measure posture.

In case it is not feasible to assess university students' sedentary behaviour through device-based measures, we recommend using the Nightly-Week-U (NWU; Moulin et al., 2020). The NWU is a validated questionnaire tailored to undergraduate students, collecting daily sedentary times in nine different domains (e.g., work, transport, socialising). Self-reports that prompt participants to examine different areas where they can accumulate sedentary time exhibit more accurate estimates than single-item self-reports (Healy et al., 2011).

2.6 Study 3: Using the Behavior Change Wheel to Understand University Students' Prolonged Sitting Time and Identify Potential Intervention Strategies

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FULL LENGTH MANUSCRIPT

Using the Behavior Change Wheel to Understand University Students' Prolonged Sitting Time and Identify Potential Intervention Strategies

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Abstract

Background Several national public health guidelines recommend individuals to minimize time spent in prolonged, continuous periods of sitting. Developing effective interventions to break up sitting, however, requires in-depth understanding of the behavior as well as identification of the key elements that need to be targeted to achieve change. This qualitative study focused on university students—a highly sedentary group—with the aim of the following: (i) exploring the factors influencing prolonged sitting time in this population; and (ii) identifying potential avenues for future intervention, based on the Behavior Change Wheel framework.

Method Eighteen ambulatory undergraduate students participated in semi-structured one-on-one interviews, using the Capability, Opportunity, Motivation, Behavior (COM-B) model and the complementary Theoretical Domains Framework (TDF) as the theoretical framework. Data were analyzed using a directed content analysis approach, followed by inductive thematic analysis.

Results All COM-B components and eight TDF domains were identified as relevant for influencing the target behavior.

Conclusion Findings suggest that interventions and policies aimed at reducing prolonged sitting time in university students should (i) raise awareness about negative health implications; (ii) address productivity concerns; (iii) provide training in behavioral self-regulation; (iv) use external reminders; (v) implement habit formation techniques; and (vi) promote social acceptability for breaking up sitting.

Keywords College students · Sedentary behavior · Sedentary time · Intervention mapping · Implementation research

Introduction

High levels of sedentary behavior—waking activities that involve sitting or reclining and a low amount of energy expenditure [1]—are associated with an increased risk for adverse health outcomes, such as all-cause mortality, type 2 diabetes, metabolic syndrome, cardiovascular disease, and depression [2–5]. Of note, the health risks of "too much" sedentary behavior have been shown to be somewhat independent of meeting current physical activity guidelines [6]. While moderate-to-vigorous physical activity can counteract the associations between sitting time and all-cause mortality, physical activity levels that are considerably higher than current recommendations seem to be needed to eliminate the negative effects of time spent sitting [7].

University students are a population sub-group at risk of accumulating high levels of sitting time, as activities such as attending lectures and studying likely involve sitting for long periods [8]. Evidence from a recent meta-analysis indicates that university students report spending 7 to 8 h sitting per

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day, with accelerometer-based estimates commonly 2 to 3 h higher [9, 10]. Research thus suggests that university students are highly sedentary [11] and that their daily sitting time is comparable with those of desk-based office workers [12]. Since many health-related behaviors are established during adolescence and young adulthood, the university years are an important period for the development of a lifelong healthy lifestyle [13].

In addition to total sitting time, the manner in which it is accumulated is also relevant. Many national public health guidelines state that individuals should not only minimize sitting time but also introduce regular breaks from long periods of sitting (e.g., Australia [14], Germany [15], the UK [16]). This recommendation is based on epidemiological and experimental evidence suggesting that accumulating sitting time in prolonged, uninterrupted bouts is more detrimental to health than accumulating sitting time in short bouts [17–22]. Previous studies reporting positive cardiometabolic outcomes have prompted breaks ranging from 2 to 4 min in length every 20–30 min of sitting [23]. However, preliminary evidence indicates that over 40% of the total sedentary bouts spent by university students exceed 30 min in duration [24].

Aside from the physiological benefits, interrupting prolonged sitting may also be relevant for cognitive performance. In previous qualitative studies with office workers, participants reported breaking up their sitting to "refresh" their mind and enhance work productivity [25, 26]. Moreover, in a recent study examining the relationship between accelerometer-based sedentary behavior and academic achievement, it was found that university students who interrupted their sitting time every 20 min during weekdays had higher academic scores [24]. Authors suggest that frequent breaks have the potential to enhance sustained attention and other cognitive operations associated with academic performance [27–29].

In summary, evidence suggests that interrupting prolonged sitting time with short physical activity breaks has the potential to benefit university students' health, as well as key study-relevant cognitive processes. Breaking up prolonged sitting, however, requires behavior change. When aiming to change behavior, it is important to rely on a comprehensive and systematic approach to intervention design, underpinned by a model of behavior and theoretically predicted mechanisms of action [30]. The Behavior Change Wheel [31] provides a theory-driven intervention development framework, including three main steps: (i) understanding the target behavior, (ii) identifying intervention functions and policy categories, and (iii) identifying intervention content and implementation options (supplementary file 1—Behavior Change Wheel [BCW] process). While other intervention design frameworks are available, the BCW is the only one that features a model of behavior, and it is sufficiently broad to cover the full range of factors that potentially affect behavior [32].

The first step within the BCW involves using the Capability, Opportunity, Motivation, Behavior (COMB) model and the complementary Theoretical Domains Framework (TDF) to identify what needs to change for the behavior to shift in the desired direction ("behavioral diagnosis"). The COM-B model is the BCW's core element and posits that behavior is part of an interacting system involving capability, opportunity, and motivation. Behavior change initiatives need to target one or more of these components in such a way as to put the system into a new configuration (i.e., is greater Capability, more Opportunity, and/or stronger Motivation required in order to achieve change?). The complementary Theoretical Domains Framework (TDF) is an integrative framework of behavior change constructs that can be used to provide a broader and more detailed understanding of the COM-B components [33]. An overview of the 14 TDF domains linking to the COM-B components is available as an online supplementary material (file 2—TDF with definitions and constructs).

Based on the results from the "behavioral diagnosis," step 2 consists of selecting appropriate intervention functions (i.e., broad categories of means by which an intervention can change behavior, such as education, training, or persuasion) and supporting policies (i.e., decisions made by authorities that influence behavior, such as fiscal measures, communication/marketing, or legislation). Having identified relevant intervention functions and supporting policies, step 3 involves specifying which behavior change techniques (BCTs) best serve the intervention functions, as well as their mode of delivery. The BCW provides guidance for steps 2 and 3 by highlighting which intervention functions, policy categories, and associated BCTs are expected to bring about change for each of the COM-B and TDF domains, based on a synthesis of 19 existing intervention development frameworks and a consensus exercise by a group of experts [32]. However, these steps cannot be conducted unless there is a proper understanding of the target behavior (step 1), so that it is possible to identify the key factors that need to be targeted in order to achieve change. That is, understanding the factors related to prolonged sitting is a critical step prior to developing effective behavior change interventions.

Very few studies to date have explored the perceptions of sedentary behavior in university students, with most of the qualitative research among working-aged adults concentrating largely on office workers [25, 26]. Deliens et al. [34] conducted focus groups to identify determinants of physical activity and sedentary behavior in undergraduate students. Students reported that their sedentary behaviors were influenced by individual factors (e.g., perceived enjoyment, self-discipline), social networks (e.g., parental control, modeling), and the physical environment (e.g., availability and accessibility of TV/computer). However, the study authors did not report using any theoretical framework and focused on overall

sedentary behavior, without exploring the factors influencing breaks in (prolonged) sedentary time. Therefore, the aims of the present qualitative study were twofold: (i) to use the COM-B and TDF approaches to provide a better insight into the factors influencing prolonged occupational sitting among university students; and (ii) to highlight potential avenues for future intervention development based on the BCW framework.

Method

Ethical approval was obtained from the University of Southern Queensland's Human Research Ethics Committee (No. H18REA237). The Consolidated Criteria for Reporting Qualitative Research (CORE-Q) was used to guide reporting (supplementary file 3).

Study Design

A qualitative study was planned using semi-structured one-on-one interviews with university students.

Sampling and Recruitment

Participants were eligible if they were (i) ambulatory, (ii) over 18 years of age, and (iii) undergraduate, fulltime, on campus students from the School of Commerce at the University of Southern Queensland (Australia). The School of Commerce, with approximately 4000 undergraduate students, offers courses in areas such as accounting and commerce, business economics, and finance. This particular school was chosen because coursework mainly involves sitting-related activities, rather than fieldwork or laboratory hours common in some other disciplinary areas. Participants had no previous relationship with any of the study authors and were informed that the interview was part of the first author's PhD project. Regarding sample size, previous recommendations on operationalizing data saturation for theory-based interview studies were followed [35]. Fifteen interviews were set as an initial recruitment target (five per study year), followed by a minimum of three additional interviews until data saturation would be reached. A purposive sampling procedure followed by a snowball sampling technique was used to recruit participants. First, a recruitment e-mail was sent to eligible students describing the study and inviting participation. Second, first-year students who had already taken part in the interviews were contacted to explore whether they could recommend other first-year students for participation (snowballing), with a limit of one student per participant. This was done to fulfill the initial recruitment target, as participants who responded to the email were predominantly second- and third-year students. Two students were recruited through snowballing. There were no dropouts during the recruitment process (i.e., all the students who expressed interest in participating were interviewed).

Interview Procedure

The interview guide was developed following existing guidance [36]. It was aimed at eliciting beliefs about the role of each TDF domain in influencing the target behavior, defined as breaking up sitting time during private academic activities with short movement breaks every 30 min (supplementary file 4—Interview script). According to the BCW, the target behavior needs to be clearly specified in terms of *who* needs to perform the behavior, *what* the person needs to change, *when*, *where*, *how often*, and *with whom*. Apart from local knowledge or research literature, a number of factors are useful when selecting or prioritizing a specific target behavior among other possible alternatives [31], including the following: (i) likely impact if the behavior were changed; (ii) likelihood of changing the behavior; (iii) potential "spillover" effects if the behavior were changed; and (iv) ease of measurement. Detailed information on how these factors were applied to select the target behavior is available as an online supplement (file 5—Definition and selection of target behavior).

The number of questions in the interview guide ranged from one to three per TDF domain. The guide consisted of open-ended, semi-structured questions, with additional prompts used to probe domains in relation to the target behavior if further clarification was needed. It was piloted with two university students. In addition, a member of the research team with expertise in qualitative research (IV) reviewed the pilot interview transcripts. Based on this pilot work, minor changes were made to address issues such as clarity and repetitiveness. For the official data collection, one-on-one interviews were arranged in a private office (on-campus). Interviews were conducted by the first author, who is a PhD candidate with a background in Sport and Exercise Psychology and has completed several qualitative research courses as part of his bachelor and master's studies. In addition, he completed a seminar focused on thematic analysis prior to the start of the study. Interested participants contacted the first author via email to set up the interview time. All participants provided written informed consent and completed a sociodemographic questionnaire prior to the interview. Two cinema tickets were offered to the participating students as a compensation.

Data Analysis

All interviews were audio-recorded, transcribed verbatim, and deidentified by the first author. The NVivo 11 software was used to facilitate the analysis. Data were analyzed using a

directed content analysis approach [37], followed by inductive thematic analysis [38]. Epistemologically, the study is situated within an essentialist/realism paradigm [39], which assumes that theories refer to real features of the world and that entities exist independently of being perceived. This epistemology guided some of the decisions during the data analyses. For example, thematic analysis was conducted at the semantic level, which means that themes were identified within the explicit or surface meaning of the students' responses, rather than at the latent or interpretative level, which tends to be used within constructivism paradigms [38].

The directed content analyses entailed a deductive approach, in which two researchers (OC & JC) read the transcripts and coded similar responses into the relevant TDF domains following a mutually agreed coding guideline to ensure the reliability of coding [36]. The coding guideline, a set of explicit statements on how the TDF is to be applied to a specific data set, was developed based on team discussion around the first three interview scripts. In instances where responses were coded in different TDF domains by the two researchers, divergences were discussed to establish consensus (81% agreement prior to discussion).

At the second (inductive) stage, one researcher (OC) used a thematic analysis approach to further analyze the data within each TDF domain. Belief statements were generated based on similarities across the participants' responses (supplementary file 6—Example coding TDF). A belief statement reflects a collection of similar responses from at least two participants that provides detail about the students' perceived role of the domain in influencing the target behavior [40]. For example, "I think it's easy to take a break," "I think I could make that work," and "It's definitely something that could be done," were responses grouped under the belief statement "Breaking up my sitting time is something that is easy to do" (TDF domain: Beliefs about capabilities). This step resulted in a list of belief statements within each TDF domain. This was reviewed by JC to ensure accurate representation of content. As a result, similar beliefs were merged together and the wording of four belief statements was changed.

Following the above analyses, the beliefs identified within each TDF domain were evaluated with respect to their likely relevance to changing the target behavior. This is known as "behavioral diagnosis" within the BCW terminology, a relevant step to determine what needs to change for the target behavior to occur. In order to judge domain relevance, three criteria were considered concurrently through a consensus discussion within the research team [36]: (i) high frequency of specific beliefs statements across participants, (ii) presence of conflicting beliefs, and (iii) evidence of strong beliefs that might impact on the target behavior. Finally, the identified TDF domains and associated belief statements were linked to intervention functions, policy categories, and BCTs likely to bring about behavior change [31]. Examples of potential intervention strategies were also provided.

Member Checking

In order to enhance the trustworthiness of results, "member checking" techniques were applied remotely after the interview [41]. First, participants received a copy of the interview transcript by email and were invited to add information or amendments if they so wished. Minimal revisions were made by two students. Second, the list of belief statements was sent to all participants asking for feedback regarding resonance with their own experiences. Five responses were received, with a general agreement about the validity of the main study findings. Based on the students' feedback, refinements were made to the wording of two belief statements.

Results

A total of 18 undergraduate students, aged 18–27 years (23 ± 2.53 years), were interviewed, of which 11 were women (Table 1). Interviews ranged from 27 to 41 min in duration, with a mean of 35.3 min per interview (SD = 4.65). Data saturation was reached after 15 interviews, with no new themes identified in the last three interviews (stopping criterion). Overall, the students reported a range of belief statements regarding the target

Table 1 Characteristics of one-on-one interview participants ($n = 18$)

Variables	% (n), mean ± SD
Gender (% of females)	61% (11)
Age	23 ± 2.53
Year of study	
1st year	28% (5)
2nd year	39% (7)
3rd year	33% (6)
Major of study	
Business economics	22% (4)
Finance	28% (5)
Accounting	17% (3)
Mixed courses (e.g., finance and accounting)	33% (6)
Race/ethnicity	
White	89% (16)
Pacific Islander	11% (2)
Employment status	
Student	83% (15)
Student and part-time job	17% (3)
Residency	
On-campus	11% (2)
Off-campus	89% (16)

behavior. The identified beliefs for each COM-B and TDF component are described below. In addition, supplementary file 7 includes a full list of belief statements, as well as their frequency across interviews and example quotes from participants.

Psychological Capability

Interviews revealed most students lacked knowledge about the adverse health risks of prolonged sitting time. There was consensus among the students that providing more information in this regard would be beneficial for motivating behavior change. Responses also highlighted that the students' decision process involved in taking breaks tended to be automatic, provoked by body sensations such as tiredness, thirst, or stiffness, rather than a conscious decision to perform the behavior. For many students, it was difficult to remember taking breaks, as university activities are absorbing and mentally demanding.

Moreover, while most students reported using different strategies to self-monitor their study and break patterns (mainly looking at a computer or wrist/smartphone clock), they rarely employed external reminders such as timers or alarms. Some students appeared to be reluctant to use these "invasive" reminders (e.g., an alarm) and preferred to use their own strategies, such as using playlists with a set duration or periodically refill their water bottles.

Reflective Motivation

Participants made conflicting comments as to whether breaking up sitting time is part of the student role/identity. Some perceived that tasks such as studying or writing assignments are the only ones central to the student role; others suggested a more holistic view where students should also take care of themselves, including taking regular breaks, engaging in regular physical activity, and having proper nutrition.

In relation to specific beliefs about capabilities, there was a general agreement among the students that interrupting sitting time during private academic activities is feasible. Students identified both positive and negative consequences of breaking up their sitting time. Over half of the participants indicated that frequent movement breaks would be beneficial for their physical health, as well as their concentration and fatigue levels. Nevertheless, there were also common concerns about the negative impact that breaks might have on performance, in terms of increased distractions.

Related to the common complaint that breaks might impair performance, many answers reflected a goal conflict between carrying out university tasks and taking frequent movement breaks. Additionally, several students' responses reflected a lack of motivation to introduce additional movement breaks to their study time.

Automatic Motivation

Some participants expressed the view that taking movement breaks does not evoke any emotional response, whereas others felt the opposite, including both positive and negative responses. Taking breaks is helpful to reduce stress and anxiety according to some students. However, students also mentioned that breaks might trigger a stress response, especially when the workload is high. Several students also highlighted that in order to perform the behavior, it needs to become an ingrained (automatic) habit. In addition, snacking or having a hot drink was viewed as potential incentives for taking breaks.

Physical Opportunity

Students identified several environmental factors influencing the frequency of breaks in sitting time. The closeness of university-related deadlines was identified as a possible source of variation, with many participants stating that they are less likely to take breaks as deadlines approach. The nature of the task was also identified as an important factor. Participants reported that it is easier to take breaks in certain tasks, such as watching a recorded lecture. A further factor influencing the frequency of breaks was the physical environment. Some students perceived that it is easier to break up sitting time at home, as opposed to the library or other shared settings.

Social Opportunity

Participants identified both positive and negative social influences for taking movement breaks. Students described that many breaks are initiated by social interactions with peers or relatives and that seeing other students taking breaks can trigger them to do so. However, some students highlighted that the presence of other individuals can prevent them from taking breaks. Reasons included fears of getting distracted or experiencing disapproval from other students.

Behavioral Diagnosis

Belief statements coded from the students' responses were subject to a behavioral diagnosis to identify what needs to change in the person and/or the environment for the behavior to shift in the desired direction. For example, the more frequent belief statements within the TDF domain *knowledge* were "having more information about the positive consequences of breaking up sitting would make me more likely to do so" and "I do not know too much about why it's important to break up my sitting time" (supplementary file 7—Belief statements). Therefore, it was surmised that one thing that needs to change for the students to break up their sitting time is knowing that accumulating sedentary time in

prolonged, uninterrupted bouts is detrimental to health. A complete behavioral diagnosis of the relevant COM-B and TDF components is presented in Table 2, including potential BCW-indicated intervention strategies and policies to address the factors influencing prolonged sitting.

Discussion

Current public health guidelines advise ambulatory individuals to minimize time spent in prolonged, continuous periods of sitting. Developing effective interventions to break up sitting, however, requires an in-depth understanding of the behavior as well as identification of the key elements that need to be targeted in order to achieve change [31]. To the best of our knowledge, the present study is the first to investigate the factors influencing prolonged occupational sitting in university students, a highly sedentary population sub-group. All COM-B components were identified by the students as relevant for influencing the frequency of breaks in sitting time. These components aligned with eight TDF domains: Knowledge; Memory, attention and decision processes; Behavioral regulation; Social/professional role and identity; Beliefs about consequences; Intentions; Reinforcement; and Social influences. By using the procedures within the BCW, we were also able to highlight relevant strategies and behavior change techniques for future intervention development.

In relation to knowledge, while students recognized general benefits of breaking up sitting, many of the adverse health risks associated with prolonged sitting were unknown. Our sample of students agreed that having more information on why it is important to break up prolonged sitting would be helpful to motivate behavior change. This is consistent with previous qualitative work [34] and highlights that "sedentary behavior" is still a relatively new concept among university students, often confused with lack of physical activity (e.g., walking, cycling). Results imply that more education is needed regarding prolonged sitting and its association with overall health. Public health messaging by universities or other organizations working with students might provide a wide-reaching and cost-effective strategy to raise awareness and change sitting patterns, especially if messages emphasize attainable, specific, and healthy alternatives to sitting such as standing or being active [42]. Education sessions have been found to be an effective behavior change mechanism to reduce sitting and increase movement throughout the day among office workers [43]. Studies are needed to examine whether such strategies are effective in the university setting.

Another common topic of discussion during the interviews was the potential effects of breaking up sitting on academic performance. Students held mixed views, with some thinking that having regular breaks can lead to improved thinking and sustained focus, while others indicated that it would harm productivity and disrupt their concentration. The concern that breaking up and reducing occupational sitting might hinder work productivity is consistent with previous studies with office workers [25, 26] and is a key belief to be targeted in order to facilitate behavior change. Interventions could try to emphasize breaking up sitting as a way of having a "mental break" from academic tasks or, alternatively, provide suggestions on how to break up sitting while still working efficiently (e.g., highlight tasks that can be undertaken standing up or walking).

Our findings highlight that social influences are relevant when it comes to breaking up sitting. According to the students, the presence of other people might inhibit breaks, due to concerns of being distracted during the break or being perceived by others as engaging in an "awkward" behavior. Concerns about the social acceptability of breaking up sitting are also common among office workers [44, 45]. Behavior change efforts need to take into account that there is an implicit norm to sit in many contexts, preventing people from changing their sitting patters in shared settings (e.g., library, lecture theaters). Finding strategies to promote the social acceptability of breaking up sitting should be an important component in the development of future interventions, especially when targeting adolescents and young adults, as research consistently shows that their health choices are greatly influenced by peers [46]. An interesting example of such strategy has been reported by the Belgian University KU Leuven, where lecturers are encouraged to appoint a "stand-secretary" at the beginning of their lectures. This is a student entitled to stand up at random times, providing a sign for other students to stand up and stretch. The initiative uses modeling by other students to raise awareness of the importance of regularly interrupting long bouts of sitting [47].

Several students referred to automatic processes such as habits and routines when discussing the target behavior. The available evidence suggests that sitting is indeed habit-based [10]. Habit is a learned behavior triggered by environmental cues with limited cognitive influence [48]. This is somewhat reflected in students' responses that indicated that breaking up sitting time was mostly an automatic decision based on body sensations such as feeling sore or tired. Previous studies have used habit formation strategies aimed at changing sitting patterns, for example, asking participants to pair standing breaks with daily habits such as talking on the phone or drinking coffee [49]. Increasing awareness and using environmental cues to break up sitting time is hypothesized to disrupt the habit of sitting, helping people to stand up and move more frequently [50]. Over time, the environmental cues might not be needed as the decision to break up sitting becomes automatic.

Finally, in order to change their sitting patters, it is important that students know how to manage and regulate their own behavior. Based on our behavioral diagnosis, we suggest that goal setting, action planning, and problem solving

Table 2 Behavioral diagnosis for target behavior "breaking up prolonged sitting time during private academic activities," along with intervention functions, policy categories, behavior change techniques, and potential intervention strategies

Behavioral diagnosis using TDF domains linking to COM-B components—what needs to change?	Intervention functions[a]	Policy categories[b]	Behavior change techniques (BCTs v1)[c]	Potential intervention strategies
Psychological capability				
Knowledge - Know that accumulating sedentary time in prolonged, uninterrupted bouts is detrimental to health - Know when and for how long break up sitting, including which activities constitute an effective break from sitting	Education, training	Communication/marketing, guidelines, service provision	Information about health consequences, information about social and environmental consequences, instruction on how to perform a behavior	- Raising awareness about the risks of prolonged sedentary behavior through educational seminars, leaflets, wall posters, or copies of public health guidelines - Provide instruction booklets or summaries of published research on break frequency and duration (dose-response), including strategies to break up sitting
Memory, attention and decision processes - Notice and remember to break up sitting - Identify the moments or situations where it is more difficult to break up sitting time	Enablement, environmental restructuring	Environmental/social planning, guidelines, service provision	Self-monitoring of behavior, adding objects to the environment, prompts/cues	- Provide a device that monitors sitting time and remind participants to move after 30 min of sustained inactivity (e.g., Darma cushion, Jawbone UP, Fitbit) - Instruct the participants to set an alarm for every 30 min or other similar strategies (e.g., use playlists with a set duration) - Use prompts at desk as visual cue to break up sitting (e.g., stickers, postcards) - Fill in diaries detailing the sitting patterns for different periods of the day (ecological momentary assessment) and prompt reflection on when is more difficult to break up sitting and why
Behavioral regulation - Set specific goals in relation to breaking up sitting time - Establish a method to monitor the frequency and duration of breaks - Analyze the barriers to break up sitting and develop strategies to overcome them, this including specific plans for moments or situations where it is more difficult to break up sitting time (e.g., when deadlines approach)	Education, training, enablement	Communication/marketing, guidelines, service provision	Self-monitoring of behavior, feedback on behavior, goal setting (behavior), review behavior goal(s), graded tasks, problem solving, action planning	- Set SMART and increasingly difficult goals to break up sitting - Provide the participant with individually tailored feedback on sedentary time in order to guide goal setting - Encourage self-monitoring and regular review of goals using a tracking device or a work-book with daily checklists (e.g., "Today, did you achieve your goal of breaking up sitting every 30 min while watching pre-recorded lectures? Yes/No. If not, what was stopping you?") - Use action planning to specify when, where, and how participants will break up sitting (implementation intentions)

Table 2 (continued)

Behavioral diagnosis using TDF domains linking to COM-B components—what needs to change?	Intervention functions[a]	Policy categories[b]	Behavior change techniques (BCTs v1)[c]	Potential intervention strategies
				- Provide guidelines with generic tips to break up sitting time and invite participants to identify strategies specific to their circumstances (e.g., have walking meetings with your classmates while discussing your next group assignment, move around the house while you check your emails on your mobile phone) - Provide free and accessible behavioral lifestyle counseling services - Prompt participants to identify potential barriers to break up sitting and discuss ways in which they could overcome them according to the IDEA problem solving (IDEA: identify the problem, develop a list of solutions, evaluate the solutions, and analyze how the plan worked)
Reflective motivation				
Social/professional role and identity - Adopt the view that taking breaks might help students to perform their role more efficiently Beliefs about consequences - Challenge the perception that breaking up sitting would disturb the student's work and concentration - Reinforce the physical and mental health benefits from breaking up sitting Intentions - Develop intentions to break up sitting during private academic activities	Education, persuasion	Communication/marketing, guidelines, service provision	Information about health consequences, information about social and environmental consequences, credible source, framing/reframing, instruction on how to perform the behavior, social comparison	- Present data supporting the idea that frequent breaks have a positive impact on health, as well as on cognitive processes related to academic performance (e.g., attention levels, mental fatigue) - Suggest that the participant might think of taking short breaks as a way to "refresh" his attention and improve performance (rather than procrastination) - Provide guidance on how to work efficiently while breaking up sitting. This might include advice on conducting walking meetings, highlight tasks that can be undertaken standing up, or recommend strategies to assist the students in getting back to their work quickly after the break (e.g., use post-its to specify what it is to be done) - Raise awareness about the fact that university students typically show higher levels of sedentary behavior compared with the general adult population and thus

Table 2 (continued)

Behavioral diagnosis using TDF domains linking to COM-B components—what needs to change?	Intervention functions[a]	Policy categories[b]	Behavior change techniques (BCTs v1)[c]	Potential intervention strategies
				should pay special attention to their sitting patterns
Automatic motivation				
Reinforcement - Establish routines and habits to break up sitting time	Environmental restructuring, training, incentivization	Environmental/social planning, guidelines, service provision	Habit formation, behavioral practice/rehearsal, feedback on behavior, self-monitoring of behavior, prompts/cues, self-reward, social reward	- Prompt rehearsal and repetition of the target behavior in the same context repeatedly so that the context elicits the behavior (e.g., ask the participant to consistently break up sitting while studying in his room) - Use environmental signposting in specific contexts to trigger breaks (visuals cues) - Prompt self-reward and deliver positive reinforcement/praise if there has been progress in breaking up sitting
Social opportunity				
Social influences - Identify places where students can break up their sitting time without being distracted by others - Promote social acceptability for breaking up sitting	Environmental restructuring, restriction	Environmental/social planning, guidelines, regulation	Restructuring the physical environment, social support (unspecified), information about others' approval, identification of self as a role model	- Advise the students to identify appropriate places to break up sitting so the participant reduces the chance to engage in competing behaviors (e.g., break up sitting by going to the bathroom, instead of going to the university canteen where there is a higher risk of being distracted by other students) - Suggest that the participant's own behavior may be an example for other students to break up their sitting time - Inform the participant that other people approves and encourages taking breaks (e.g., posters or booklets with motivational quotes from other students)

[a] The Behavior Change Wheel describes nine potential intervention functions. This is broad categories of means by which an intervention can change behavior, including education, training, persuasion, incentivization, coercion, restriction, modeling, environmental restructuring, and enablement [32]

[b] The Behavior Change Wheel describes seven policy categories that are likely to be effective in supporting each intervention function. The policy categories represent types of decisions made by authorities that help to support and enact behavior change, including communication/marketing, guidelines, fiscal measures, regulation, legislation, environmental/social planning, and service provision [32]

[c] A Behavior Change Technique (BCT) is an "active ingredient" of change and is defined as an "observable, replicable, and irreducible component of an intervention designed to alter or redirect causal processes that regulate behavior" [32]. The Behavior Change Technique Taxonomy version 1 (BCTTv1) includes 93 BCTs grouped within 16 categories and can provide a greater level of intervention detail for synthesis, comparison, and replication of studies

are potential self-regulatory skills that can assist the students in breaking up sitting. Indeed, in a review exploring BCTs that have been effective in reducing sitting time among adults, self-regulatory skills training was identified as a particularly promising strategy, along with restructuring the physical environment [51]. Changes in the physical environment usually include provision of standing desks and use of prompts or other environmental cues. In our study, students reported that the use of external reminders would be useful to notice and remember to break up sitting. However, certain strategies (e.g., setting an alarm) do not seem acceptable for some students and

intervention developers might need to take a personalized, case-by-case approach.

Recommendations for Future Research and Intervention Development

Sitting is a highly prevalent behavior, occurring in different contexts and with varied purposes. This presents a challenge for researchers and intervention developers; there is a balance between being highly behaviorally specific (to precisely identify what factors need to be changed) and being general enough to be relevant to a range of settings (maximizing the likely impact if the behavior were to be changed). Based on the BCW framework, it is argued that a specific description of the behavior helps to determine the sources of implementation problems, pinpointing what needs to be changed, thus increasing the chances for the intervention to be effective [32]. For example, an intervention to promote breaks from occupational sitting time might need to target different factors depending on the context (i.e., breaks during private academic activities vs breaks during lectures). Unlike private study time, breaking up sitting during lectures might require policy and curriculum changes, along with modifications in how lecture theaters are built. That is, despite both behaviors qualifying as occupational sitting, they would require a specific behavioral diagnosis and, potentially, different intervention approaches. Researchers should consider this issue and make their own decisions on the appropriate level of behavioral specificity for sedentary behavior.

Intervention developers should also consider the specific behavioral target(s). Sedentary behavior interventions typically focus on breaking up sitting time, reducing overall sitting, or changing both behaviors simultaneously. Some authors argue that, for university students, breaking up existing occupational sitting time into shorter bouts might be more feasible than displacing large volumes of daily sitting time to standing or moderate-to-vigorous physical activity [52]. We consider that the two behaviors are closely related and that some of the strategies identified in the present study could also be applied in sitting time reduction interventions (e.g., provision of information about health consequences, self-regulatory skills training, use of environmental cues). Previous studies have explored the factors influencing overall sitting time in university students [34]. These could be used to complement our findings and inform interventions aiming at both reducing and breaking up sitting.

Future studies might also explore the influences of non-occupational sitting and assess whether (i) they differ from the factors associated with variation in occupational sitting, and (ii) change is more or less feasible (i.e., students perceive it might be easier to introduce change in one or the other). Moreover, many participants believed that breaking up sitting might have negative implications for working effectively. While some evidence exists suggesting the opposite [24], this is still an understudied area. Further research including measures of productivity is required to strengthen the case for reducing prolonged sitting in the university setting.

Throughout our study, we provided a list of BCTs likely to bring about change for the target behavior, based on a behavioral diagnosis framed within the COM-B and TDF components. However, additional decisions need to be made regarding different intervention dimensions such as mode of delivery (face-to-face or distance?), duration (over what period?), and intensity (what is the number and frequency of contacts during the intervention?). In order to determine the most appropriate mode of implementation, researchers may need to take different factors into account, including the particular characteristics of the target behavior and population group, time and financial resources, as well as evidence gathered from local sources and the research literature.

Strengths and Limitations

A strength of this study is that we used a comprehensive and systematic approach to identify theory-based factors influencing prolonged occupational sitting time in ambulatory university students. Drawing on the COM-B model and associated TDF domains provides a useful framework for understanding behavior and determining the content of future interventions. Moreover, this study adds evidence to the limited literature investigating sedentary behavior in university students. So far, research on sedentary behavior among working adults has largely focused on office workers. Our study has also some limitations that need to be considered. Results are based on a predominantly white sample of undergraduate students. Therefore, findings may not be applicable to all university students. Additionally, broad sociocultural factors that may influence study habits (e.g., socioeconomic status) were not explored in our interviews and need to be incorporated in future research.

Conclusion

A wide range of beliefs aligning with the COM-B and TDF components were identified by the students as likely to influence their time spent in prolonged occupational sitting. By using the BCW, our study provided a theory-driven foundation to generate possible behavior change strategies directly from these beliefs. Findings suggest that the following should be key components in future interventions aimed at reducing university students' prolonged occupational sitting: (i) raising awareness about the negative consequences of prolonged sitting, (ii) addressing productivity concerns, (iii) providing training in behavioral self-regulation, (iv) making use of external reminders, (v) implementing habit formation techniques, and (vi) promoting social acceptability for the

behavior. Future studies should examine the effectiveness and practicability of these strategies, as well as their potential relevance to other sedentary behaviors and contexts.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Informed Consent Informed consent was obtained from all individual participants included in the study.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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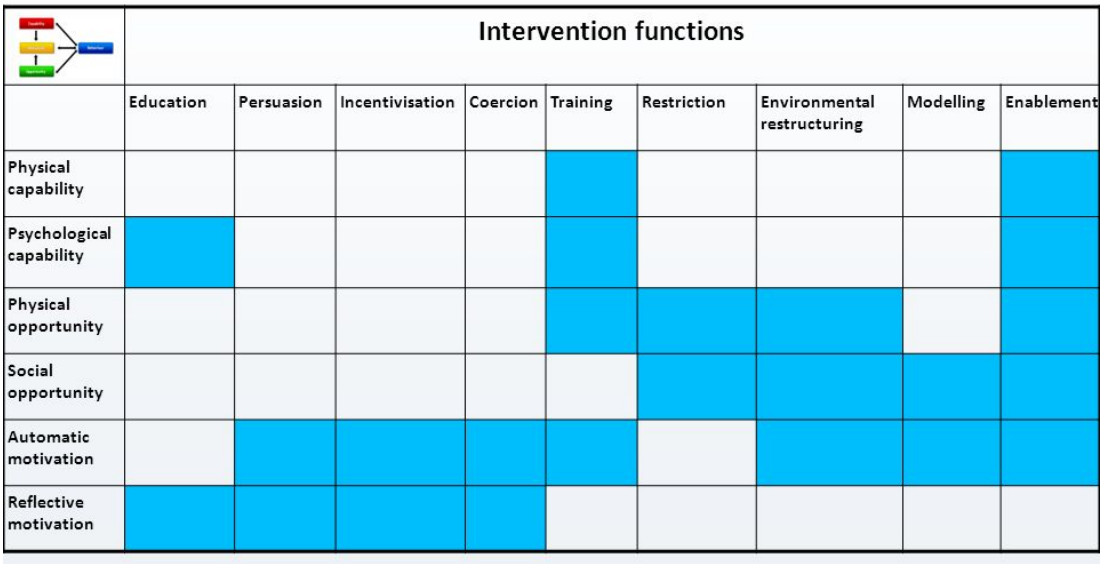
2.7 How the Publication Contributes to the Advancement of the Research Area

Both epidemiologic (Bellettiere et al., 2019; Diaz et al., 2017) and experimental evidence (Benatti & Ried-Larsen, 2015; Todd et al., 2007) suggests that accumulating sedentary time in prolonged, uninterrupted bouts is detrimental to health. Specific to occupational sedentary behaviour, breaking up long periods of sitting might also be relevant to enhance attention and cognitive performance (Felez-Nobrega et al., 2018). Developing effective behaviour change interventions to break up sitting, however, requires time and effort to fully understand behaviour and its determinants (a critical and often overlooked step in intervention development). Through this study, we provided theory-based insights into the factors influencing prolonged sedentary time in university students and highlighted potential avenues for future behaviour change efforts. Drawing on the BCW provides a comprehensive and systematic framework for understanding behaviour and determining the content of future interventions. Apart from the intervention content, future studies should also consider exploring the students' preferred mode of delivery for the intervention (e.g., face-to-face, digital, individual, group-based), as this is an important feature that contributes to the intervention success and scalability.

Chapter 3 From Behavioural Diagnosis to Intervention Design and Evaluation

3.1 Overview of the Chapter

The research findings from Study 3, together with previous literature (e.g., Deliens et al., 2015), allowed the research team to further understand sedentary behaviour in the university settings and the factors influencing it. Based on what is understood about the behaviour, the BCW provides a systematic way of identifying relevant intervention functions, which can then be translated into specific techniques for changing behaviour (Figure 5). Once the intervention content was specified (Michie et al., 2013), team decisions were made regarding the mode of delivery for the intervention, taking into account the APEASE criteria (Affordability, Practicability, Effectiveness/cost, Acceptability, Side-effects/safety, and Equity), as well as previous interventions targeting university students' sedentary behaviour. This resulted in an individually targeted intervention, delivered through a single one-on-one session and automated daily text messages, and including educational and environmental restructuring (prompts/cues) components.



	Intervention functions								
	Education	Persuasion	Incentivisation	Coercion	Training	Restriction	Environmental restructuring	Modelling	Enablement
Physical capability					■				■
Psychological capability	■				■				■
Physical opportunity					■	■	■		■
Social opportunity						■	■	■	■
Automatic motivation		■	■	■	■		■	■	■
Reflective motivation	■	■	■	■					

Figure 5. Capability, Opportunity, and Motivation components (COM-B model) mapping with the different intervention functions included in the Behaviour Change Wheel (adapted from Michie et al., 2014).

Upon deciding on the intervention content and mode of delivery, an important step before the start of a large-scale, effectiveness trial is pilot testing. A pilot trial (also known as feasibility study) is a small-scale study carried out in

preparation for a larger investigation. Pilot trials are used to test key elements of the study, including retention and recruitment strategies, data collection procedures, and intervention delivery (Cook et al., 2016, Thabane et al., 2010). Conducting a pilot trial might lead to subsequent refinements of the intervention and its implementation/assessment, increasing the likelihood of delivering a successful future randomized controlled trial (Moore et al., 2015). Thus, as part of the PhD project, it was decided to conduct a pilot trial examining the feasibility and preliminary effects of the BCW-informed intervention. The pre-print version of the study is presented below.

3.2 Study 4: Feasibility of Reducing and Breaking up University Students' Sedentary Behaviour: Pilot Trial and Process Evaluation

Feasibility of reducing and breaking up university students' sedentary behaviour: Pilot trial and process evaluation

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Abstract

Background: Accumulating high levels of sedentary behaviour has been linked to poor health outcomes. This study aimed to examine the feasibility and preliminary, short-term effects of a theory-based intervention aimed at reducing total and prolonged sedentary behaviour in university students.

Design: A quasi-experimental (pre-post) pilot study. Methods: Nine ambulatory undergraduate students (Mean age = 22 ± 2.32) received an individualised consultation session and daily text messages targeting sedentary behaviour. The Behaviour Change Wheel framework was used to guide the intervention design process. Outcomes were assessed over 6 days in pre- and post-intervention periods and included accelerometer-based (activPAL) and self-reported (Nightly-Week-U) total sedentary time, as well as accelerometer-based number of steps and prolonged sedentary time. Students took part in a process evaluation interview upon completing the trial.

Results: From pre- to post-intervention, there was a significant reduction in accelerometer-based total and prolonged sedentary time during weekend days. In addition, there was a significant increase in accelerometer-based standing time and steeping during weekend days. There were no statistically significant changes during weekdays. Process evaluation results indicated that the intervention and its assessment is feasible. Reductions in sedentary time were likely to be mediated by changes in the student's reflective motivation and psychological capability.

Conclusions: Findings from this small, short-term intervention suggest that a single one-on-one session, together with automated text messages, may help university students reduce sedentary behaviour and enhance movement during weekend days. Additional strategies to maximise the intervention effects are warranted. A larger, controlled trial assessing sedentary behaviour over a longer period is needed to establish effectiveness.

Introduction

Sedentary behaviour refers to any waking activity involving low energy expenditure and where sitting, reclining, or lying is the dominant posture (Tremblay et al., 2017). Accumulating high levels of sedentary behaviour has been linked to negative physical and mental health outcomes (Biswas et al., 2015; Patterson et al., 2018; Zhai et al., 2015). As a result, in addition to promoting aerobic and muscle-strengthening activities, public health guidelines now recommend individuals minimise the amount of time spent sedentary, as well as break up long periods of sedentary behaviour (Australian Department of Health, 2014; UK Department of Health, 2019). University students are highly sedentary, as most of their 'working' hours are spent studying or in class (Castro et al., 2020a). However, interventions targeting sedentary behaviour in student populations are scarce and lack theory guidance (Cotten & Prapavessis, 2016; Jerome et al., 2017; Tardif et al., 2018).

To develop effective behaviour change interventions, it is important to have a theoretical understanding of what behaviour is and how behaviour change works, so the relevant mechanisms of change can be appropriately targeted (Michie et al., 2008). The Behaviour Change Wheel (BCW) is a theory-driven framework that provides a systematic way of developing interventions (Michie et al., 2014). This framework involves using the Capability, Opportunity, Motivation, Behaviour (COM-B) model and the complementary Theoretical Domains Framework (TDF) to identify what needs to change for the behaviour to shift in the desired direction ('behavioural diagnosis'). The COM-B model posits that changing behaviour involves changing one or more of the following: capability, opportunity, and motivation (i.e., is greater Capability, more Opportunity, and/or stronger Motivation required to achieve change?). The TDF is an integrative framework of behaviour change constructs that can be used to provide a more detailed understanding of the COM-B components (Cane et al., 2012). Based on the 'behavioural diagnosis' results, structured around the COM-B and TDF, the BCW provides guidance regarding which intervention functions and associated Behaviour Change Techniques (BCTs) are likely to bring about change for a given behaviour (Michie et al., 2011). An overview of the 14 TDF domains linking to the COM-B components is available as online supplementary material (file 1 - TDF).

Once the intervention has been designed, a key step before the start of a large-scale trial is pilot testing (Steckler et al., 2002). Conducting a pilot trial is helpful for several reasons, including identifying identify recruitment or budget problems, optimising the intervention content and mode of delivery, informing on the accuracy of the measurement tools, and/or estimating effect size (Thabane et al., 2010). At this stage, a process evaluation can have an important role in understanding the feasibility of the intervention and refining its design and evaluation (Oakley et al., 2006). The updated UK Medical Research Council (MRC) guidelines provide directions on how to structure the process evaluation of pilot trials (Moore et al., 2015). This framework recommends: (i) assessing the acceptability of implementation structures; (ii) testing intermediate mechanisms (to get a better understanding of the pathways between intervention and outcomes); and (iii) identifying contextual factors associated with variations in outcomes. All these are critical to inform the intervention's future scale-up efforts.

The aims of the present study were twofold: (i) to explore the preliminary, short-term effects of a BCW-informed intervention to reduce total and prolonged sedentary behaviour among a small sample of university students (outcome evaluation); and (ii) to assess the feasibility of the intervention and its intended assessment (process evaluation).

Methods

Study Design

Data for this quasi-experimental (one group pre-test/post-test) trial were collected in February 2020. Participants underwent a 6-day baseline assessment of sedentary time, took part in a one-on-one intervention session, and completed a 6-day post-intervention assessment immediately following the one-on-one session. In addition, a process evaluation interview was conducted at the end of the 6-day post-intervention assessment. Both pre- and post-intervention assessments included four weekdays and two weekend days. Participants provided informed written consent and were offered a $40 gift voucher upon completion of the trial. Ethical approval was obtained from the University of Southern Queensland's (USQ) Human Research Ethics Committee (No. H19REA314).

Participants

Participants were eligible if they were aged 18 years or over, ambulatory, and studied on-campus and full-time at the USQ's Faculty of Business, Education, Law and Arts. Participants were invited to participate via an announcement on the university-wide online portal. Interested participants contacted OC through email to arrange the initial on-campus meeting.

Intervention

The first stage within the BCW consists of identifying, in terms of the relevant COM-B and TDF components, what needs to change in the person and/or the environment to achieve the desired behaviour. This process, known as 'behavioural diagnosis', is typically informed by an analysis of local sources and/or the scientific literature (Michie et al., 2014). For the present study, two previous qualitative studies with university students were used to draw an accurate picture of sedentary behaviour and its influences specifically for this population subgroup, highlighting relevant areas for change (Castro et al., 2020b; Deliens et al., 2015).

The behavioural diagnosis results are detailed in Table 1 (first column: 'Behavioural diagnosis using TDF domains linking to COM-B components – What needs to change?'). A list of BCW-indicated BCTs likely to be effective in changing sedentary behaviour was generated based on the behavioural diagnosis and discussed among the study authors. For example, a common finding in previous qualitative studies is the idea of a goal conflict between carrying out the university tasks and reducing and breaking up sedentary behaviour (which relates to 'reflective motivation' within the COM-B and, more specifically, 'belief about consequences' within the TDF). Thus, it was surmised that something that needs to change is the students' perception that reducing and breaking up sedentary behaviour during academic activities will disturb their work and concentration. Following with the above example, the BCW suggests a series of BCTs that are thought to be potentially useful when changing 'beliefs about consequences', such as 'information about health consequences', 'credible source', or 'framing/reframing'. Therefore, these techniques were incorporated into the intervention content, as part of both the one-on-one session and the text messages. A similar process was followed with the rest of the behavioural diagnosis results (Table 1).

Once the intervention content was developed, team decisions were made regarding the intervention delivery, taking into account practical criteria (e.g., time and resources available) as well as previous intervention studies targeting sedentary behaviour. For example, Cotton and Prapavessis (2016) found that sending regular text-messages is an effective strategy to reduce university students' sedentary behaviour. In addition, previous studies provide support for the efficacy of a single face-to-face intervention session in reducing sedentary behaviour in older adults (Fitzsimons et al., 2013; Gardiner et al., 2011). Thus, we decided to use a one-on-one session, together with automated text-messages, as the mode of delivery for the intervention.

The one-on-one session lasted approximately 45- to 60-minutes and was facilitated by OC, who is a PhD candidate with a background in psychology and has completed different qualitative and quantitative research courses as part of his bachelor and master's degree studies.. The session was structured around an intervention workbook, which included an introduction with key concepts/health effects of sedentary behaviour and three distinct activities: (i) review of accelerometer-assessed sedentary behaviour from the 6-day baseline assessment (including normative feedback); (ii) decisional balance exercise to elicit change talk (pros and cons of changing sedentary behaviour); and (iii) suggested strategies to reduce and break up sedentary time (supplementary file 2 – intervention workbook). The suggested strategies were developed using the behavioural diagnosis results (Table 2), as well as 'general tips' for changing sedentary behaviour found in previous intervention studies (Maylor et al., 2018; Neuhaus et al., 2014). Students were also introduced to several freely available resources that might facilitate reducing and breaking up sedentary time (e.g., posters and other visual cues, mobile and computer apps).

In addition to the individual session, participants received a series of daily text-messages during the 6-day post-intervention assessment. A total of 24 messages (four per day) were sent daily at fixed intervals: morning (10:00 am), afternoon (14:00 pm & 17:00 pm) and evening (20:00 pm). These served two purposes: (i) to act as prompts/reminders for the students to reduce and break their sedentary time; and (ii) to reinforce the key messages delivered during the face-to-face session (supplementary file 3 – list of intervention messages). The text messages were sent

automatically via an SMS scheduling app and covered four broad areas: nudge messages (i.e., generic break up prompts such as 'If you've been sitting for more than an hour consider getting up and move! Try walking around or doing some light stretching'), health-related messages (e.g., 'Walking burns 5 times the calories that sitting does. Take every opportunity to walk around!'), psychological wellbeing and productivity messages (e.g., Breaking up sitting time with short walking breaks has been shown to counteract mental fatigue, in comparison with continuous sitting'), and suggested strategies to reduce and break up sitting (e.g., 'You can use habit formation strategies to change your sitting patters. For example, try to consistently pair standing breaks with daily habits such as texting on the phone or drinking coffee'). The specific wording and 'tone' of the messages were developed following evidence-based recommendations for effective sedentary behaviour messaging: Alley et al. (2019) suggest messages may be more effective at reducing sedentary behaviour if they are achievable, specific and recommend healthy alternatives to sitting (e.g., standing or being active). In addition, previous intervention studies using sedentary behaviour messaging with university students were used to help generate ideas on the SMS content (Cotten & Prapavessis, 2016; Mnich et al., 2019).

Outcome measures

Outcomes included accelerometer-assessed and self-reported sedentary time, as well as accelerometer-assessed number of steps and prolonged sedentary time (i.e., time spent in sedentary bout durations of ≥30 min and ≥60 min; number of sit-to-stand transitions). In addition, participants completed a sociodemographic questionnaire during the first face-to-face meeting.

The accelerometer used was the activPAL (PAL Technologies, Glasgow, UK), which provides steps and activity counts, as well as inclinometer information used to determine posture. The activPAL is considered the gold standard for the measurement of sedentary behaviour (Koster et al., 2016; Kozey-Keadle et al., 2011) and has demonstrated excellent reliability and validity in measuring sitting, standing, and stepping (Sellers et al., 2016). The device is worn on the midpoint of the anterior aspect of the thigh and is attached to the skin using a hydrogel adhesive pad. The accelerometer can be waterproofed with a small flexible sleeve. Participants received verbal and written instructions to attach the activPAL during the first session and

were asked to wear the device on a continuous wearing protocol (i.e., during sleeping and waking hours, including water-based activities). In addition, participants filled in a paper-based daily log collecting data on waking/sleeping hours and wear-related information (e.g., removal periods and reasons).

The self-report tool used to assess sedentary time was the Nightly-Week-U (NWU). The NWU is a validated questionnaire aimed at collecting daily sedentary times of undergraduate students in nine different domains, including work, transport, or socializing (Moulin et al., 2020). Self-reports that prompt participants to examine different areas where they can accumulate sedentary time exhibit more accurate estimates than single-item self-reports (Healy et al., 2011). In addition, a noteworthy element of the NWU is that participants complete the questionnaire at the end of their day (right before retiring to bed), which has been shown to reduce recall bias and increase accuracy compared to weekly self-reported measures (Moulin et al., 2020). The NWU was filled in daily, together with the activPAL log (supplementary file 4 – daily log).

Process evaluation interview

An interview schedule was developed around the three categories included in the MRC process evaluation framework (i.e., implementation, intermediate mechanisms, and context). Areas explored included: strategies used to reduce and break up sedentary behaviour, facilitators and barriers to changing behaviour, perceived mechanisms of action, feedback on the intervention delivery and measurement tools, and role of external factors in influencing sedentary patterns. The schedule consisted of semi-structured, open-ended questions, with additional prompts used if further clarification was needed (supplementary file 5 – interview schedule). For the 'intermediate mechanisms' section of the interview, a list of possible mechanisms of action (i.e., processes through which behaviour change occurs) was generated based on the Theory & Technique Tool (Michie et al., 2018). This online tool consists of a heat map with 74 BCTs (y-axis) and 26 mechanisms of action (x-axis). Each resulting cell uses a colour code to represent the strength of the link between a BCT and a mechanism of action, based on data triangulation from a literature synthesis study (Carey et al., 2019) and an expert consensus study (Connell et al., 2019). Considering the 17 BCTs included in the intervention, 14 mechanisms

of action were identified as likely to mediate the effect of the intervention on sedentary behaviour and explain how change occurred. A statement was generated for each mechanism of action (e.g., Beliefs about consequences: "I've changed my sitting patterns over the past week because I'm now aware of the negative consequences of too much sitting"). During the interview, students were asked to rate their agreement with the statements (from 0 to 10), and invited to add additional insights on how the specific mechanism influenced (or not) their sedentary behaviour patterns (supplementary file 6 – mechanism of action questionnaire).

The initial versions for the interview schedule and the mechanisms of action questionnaire were developed by OC and later refined based on feedback from a member of the research team with expertise in qualitative research (IV). Also, the interview was piloted with one university student before the start of the data collection. Minor changes were made to the wording of two questions based on this pilot work.

Data analysis

Potential changes in sedentary behaviour patterns and the number of steps from pre- to post-test were examined using paired t-tests (normally distributed data) or Wilcoxon tests (non-normally distributed data). The data normality assumption was deemed plausible for all activPAL outcomes, based on statistical (Shapiro-Wilk Test) and graphical (Q-Q plots) procedures, but was rejected for the NWU dimensions (Mishra et al., 2019). The alpha level for significance testing was set as $p \leq 0.05$ (two-tailed). In addition, effect sizes (hedges' g and rank-biserial correlation) were calculated to describe the magnitude of differences between pre- and post-test, with 0.2, 0.5, and 0.8 indicating a small, medium, and large effects, respectively (Lakens, 2013). All analyses were conducted in SPSS v26.0 (SPSS Inc., NY, USA).

ActivPAL data were exported (EventsXYZ.csv file) and processed following existing recommendations (Edwardson et al., 2017). The activPAL and Excel software packages were used to facilitate the analysis. All events during the self-reported sleeping period were excluded. If not reported (n = 2 days), the sleeping period was estimated by visually scanning the time-stamped events file (i.e., identifying cessation and resumption of standing/stepping events during night hours). After removing the sleeping period, the following were summed up for each day and

means were calculated from valid days (including separate means for weekdays and weekend): total sedentary time, prolonged sedentary behaviour (sitting/lying bouts of ≥30 min and ≥60 min), number of sit-to-stand transitions, and number of steps. Consistent with previous studies (Edwardson et al., 2017), a day was considered valid if wear time comprised ≥80% of reported waking hours. As with the activPAL data, means for the different dimensions of the NWU questionnaire were calculated for pre- and post-test assessments and inputted in the analyses.

For the process evaluation data, all interviews were audio-recorded and transcribed verbatim by OC. Inductive thematic analysis was applied to identify and organise relevant themes (Braun & Clarke, 2006; 2019). First, participants received a copy of the interview transcript by email and were invited to add information or amendments if they so wished (member checking). Minimal revisions were made by two students. Second, each transcript was coded by OC, with previous transcripts revisited as new codes were identified. Third, codes were grouped into themes/sub-themes and reviewed through rereading full transcripts and coded material. NVivo 11 software was used to facilitate the analysis. To judge theme relevance, the specific frequency of participants endorsing each theme was considered. Epistemologically, qualitative analyses were situated within an essentialist/realism paradigm (Bhaskar, 2013). For the mechanisms of action questionnaire used during the interview, means for each dimension were calculated.

Results: Outcome evaluation

Nine participants provided informed consent and received the intervention (Table 2). In general, the students provided complete outcome data at both time points (i.e., baseline and post-intervention). For the NWU, two days from two different participants were excluded from the analysis due to missing data. For the activPAL, one day was excluded from the analysis due to accelerometer malfunction (battery fault). Mean wear time was 98.8% (± 3.1). Program retention was 100% and there were no adverse events reported.

Changes in accelerometer-derived sedentary time, standing and moving

Table 3 shows the descriptive statistics for each of the activPAL outcomes, including a pre-post comparison (paired t-tests). From baseline to post-intervention, there was a statistically significant reduction in total and prolonged sedentary time

during weekend days (mean baseline [SD], mean change, p value – [a] sedentary time: 11.06 hr/d [1.6], –1.65 hr/d, p = 0.005; [b] Time spent in sedentary bouts >30 min: 7.2 hr/d [2.1], –1.65 hr/d, p = 0.007; [c] Time spent in sedentary bouts >60 min: 4.25 hr/d [2.36], –2.03 hr/d, p = 0.002). In addition, there was a statistically significant increase in time spent standing and stepping during weekend days (standing time: 2.86 hr/d [1.36], 1.1 hr/d, p = 0.019; stepping time: 1.28 hr/d [0.33], 0.55 hr/d, p = 0.003; number of steps: 5585.11 [1554.06], 2513.33, p = 0.004). There were no statistically significant changes in sedentary time, standing, or moving across the whole 6-day period or during weekdays.

Changes in self-reported sedentary time

Table 4 shows the descriptive statistics for each of the NWU dimensions, including a pre-post comparison (related samples Wilcoxon Signed Rank Test). From baseline to post-intervention, there was a statistically significant reduction in total self-reported sedentary time across the whole 6-day period and during weekend days (median baseline hours per day [IQR], median change, p value – [a] sedentary time: 10.31 hr/d [2.14], –1.3 hr/d, p = 0.021; [b] sedentary time during weekend days: 10.69 hr/d [3.25], –1.92 hr/d, p = 0.021). In addition, there was a statistically significant increase in time spent studying during weekdays (1.73 hr/d [1.75], 1.37 hr/d, p = 0.028). There were no statistically significant changes in self-reported sedentary time for the rest of the NWU dimensions.

Results: Process evaluation

Interviews ranged from 23 to 38 minutes in duration, with a mean of 30.8 minutes per interview (± 4.67). Overall, four main themes where identified: 'implementation', 'context', 'mechanisms of action', and 'behaviour change experience'. These themes are presented below, including relevant first and second level sub-themes (see Table 5 for a complete list of themes, together with example quotes from participants and frequency counts). In addition, the summary results from the mechanism of action questionnaire are provided in Figure 1.

Theme 1: Implementation

Regarding the data collection, interviews with students showed that they were generally positive about the activPAL and felt that it did not affect their daily

activities. However, the number of wear days was identified as a barrier to trial participation by some participants. There was consensus among the students that the text message reminders were beneficial for the completeness of the daily logs and NWU questionnaire.

Regarding the intervention, there was a clear positive response towards the one-on-one session, which was described as highly informative and useful to achieve behaviour change. The intervention text messages were also well received, although two students reported that they were not relevant to them because of limited smartphone use. Participants had very few ideas or recommendations to improve the intervention content or delivery, but one student suggested the information provided should be more tailored to university students. Approximately half of the students used the provided poster as a visual cue to reduce and break up sedentary behaviour, while suggested apps were generally not used.

Theme 2: Context

Students identified several environmental factors influencing their sedentary behaviour patterns. University workload was highlighted as a potential source of variation, with most participants stating that they are less likely to reduce and break their sedentary time as workload increases. The weather was also identified as a relevant factor. Participants linked extreme weather conditions (i.e., hot in summer, cold in winter) to higher levels of sedentary behaviour. To a lesser extent, students also claimed that they tend to accumulate more sitting during days off work (non-university related), reflecting some sort of compensation behaviour. Finally, a majority of students expressed the view that both trial weeks (pre and post) were comparable, in terms of external influences to their sedentary behaviour.

Theme 3: Behaviour change experience

The key strategies used by the students to reduce and break up sedentary behaviour centred on performing daily activities while standing or moving (rather than sitting), doing more household work, and using visual cues (poster or post-its). Moreover, some students tried to incorporate active time into their daily commutes (e.g., parking the car further away). Participants also reported a series of barriers that made behaviour change difficult. These included competing demands between reducing sedentary time and studying (i.e., goal conflict), as well as difficulties

remembering to reduce or break up sedentary behaviour while performing other activities. Additionally, most students' responses reflected that it is easier to change sedentary behaviour patterns during recreational, non-university related activities.

While all participants claimed to have reduced the amount of time spent sedentary during the post-intervention period, there were differences in how sedentary behaviour was displaced. Some participants substituted sedentary behaviour mainly with walking, whereas others replaced sedentary behaviour with standing or a combination of walking and standing activities. All students stated that they would actively try to be less sedentary in the future.

Theme 4: Mechanisms of action

For most participants, the knowledge learnt from the intervention had a powerful impact on their behaviour change process. The one-on-one session and supporting text messages were generally viewed as successful in raising awareness of the physical and mental health consequences of too much sitting and for increasing motivation to make a change. As a result, most answers reflected a negative attitude towards excessive sedentary behaviour, developed as a result of trial participation, and an intention to introduce changes.

The students highlighted the activPAL feedback provided during the one-on-one session and the text messages as two intervention components that were particularly helpful in their quest to reduce and break up sedentary behaviour. To a lesser extent, students also attributed their behaviour change success to the use of self-regulation strategies (i.e., goal setting and self-monitoring). There were conflicting views, however, on whether the intervention assisted the students in developing new skills to reduce and break up their sedentary behaviour. Some students did not consider that they have learnt new skills but rather used existing strategies more often. Similarly, students hold mixed views as to whether reducing and breaking up sedentary time is part of their student role/identity.

Other mechanisms of action explored during the interviews (i.e., reinforcement, subjective norms, social influences, and self-image) did not seem to have substantially contributed to the students' behaviour change processes. For example, only two students reported having used incentives to reinforce behaviour change efforts. Similarly, most students did not mention any social influence that had

positively contributed to reducing and breaking up their sedentary behaviour, although many claimed that they have tried to 'convince' their family and friends to move more and sit less.

Mechanism of action questionnaire

As shown in Figure 1, the mean scores for the different mechanisms of action statements (i.e., reasons for change) ranged from 2.8 to 9.2, on a scale of 0 to 10 (with 0 meaning that the specific statement did not apply to the student's behaviour change process at all, and 10 meaning that it completely reflected the student's reason for change). Statements referring to feedback processes, motivation, intentions, beliefs about consequences, knowledge, behavioural cueing, and attitude towards the behaviour received a mean score above five (scale's midpoint). Statements referring to social/professional role, behavioural regulation, and skills received a mean score of (or close to) five. Finally, statements referring to self-image, reinforcement, social influences, and subjective norms received a mean score below five.

Discussion

The purpose of this study was to assess the feasibility and preliminary, short-term, effects of an intervention informed by the Behaviour Change Wheel aimed at reducing total and prolonged sedentary behaviour in university students. Among our small sample of university students, both accelerometer and self-reported findings suggest that a one-on-one session, together with daily text messages, might encourage students to reduce sedentary behaviour and increase standing and steeping during weekend days. Effect sizes were large for the accelerometer data (activPAL), and small-to-medium for the self-report data (NWU questionnaire). However, there were no significant changes in sedentary behaviour, standing, or stepping across the whole 6-day period or during weekdays.

While limited statistical power may have made it difficult to detect statistically significant changes, results suggest the intervention had different effects depending on the day of the week. Based on the process evaluation results, we interpret this might be because of the type of activities predominantly performed during weekend and weekdays (i.e., recreational and occupational, respectively). Students reported finding it easier to change their sedentary behaviour patterns

during leisure activities, rather than during university-related tasks. This is due to common concerns about the negative impact that reducing and breaking up occupational sitting might have on performance, similar to those reported in previous qualitative studies with university students (Castro et al., 2020b) and office workers (Cole et al., 2015; MacDonald et al., 2018).

Considering the students found it particularly difficult to reduce and break up their sedentary time during occupational activities, another factor that might have contributed to the lack of change in sedentary behaviour during week days is the reported increase in time spent carrying out academic activities for that period. From baseline to post-intervention, 'studying' during weekdays was the only self-reported NWU dimension that experienced a significant change. Even if students also undertake academic activities at home during the weekend, it is plausible that these allow for more active choices, compared to attending lectures or studying in the library on weekdays (where students might not have the option or might find it more difficult, to reduce and break up their sedentary behaviour). The latter may include social normative influences that reduces the chances of students making changes (Pachu et al., 2020).

Taken together, these findings suggest that a more complex intervention, involving relevant staff from the university setting and wider environmental changes, are likely to be needed to maximise behaviour change (especially for occupational sedentary behaviour during weekdays). One potential avenue for change is university lecturers, who are in a unique position to highlight the importance of reducing and breaking sedentary behaviour and promote social acceptability for changing behaviour (e.g., implementing active breaks during their lectures). Yet, the interviews reflected that this is not currently being emphasised by lecturers, student wellness advisors, or any other university staff members. Future research should examine how sedentary reduction interventions could be conducted utilising these staff and their potential to be facilitators of behaviour change. In addition, the introduction of sit-to-stand desks and active stations in university classrooms and libraries is an effective approach to reducing sedentary behaviour in university students (Bastien et al., 2018, Jerome et al., 2017), while generally causing little to no disruption in productivity and academic-related outcomes (Rollo et al., 2019; Smith & Prapavessis, 2017). Studies indicate that a large portion of students believe

these environmental opportunities should be made available in university classrooms (Smith et al., 2018). However, it should be noted that incorporating such environmental changes are not always feasible given the increased intervention cost.

In addition, the fact that students found it easier to change their sedentary behaviour patterns during leisure, non-academic activities might be used in future interventions as a way to provide a graded task approach to behaviour change. Targeting sitting time reductions for this type of activities (mostly performed in weekends) might be a good start and make behaviour change more likely, contributing to change the students' attitude towards sedentary behaviour and increase self-efficacy for reducing sitting (which then may well be transferred to occupational activities during weekdays).

Process evaluation results indicated that the intervention protocol and its assessment is feasible and acceptable. Some students felt, however, that the number of days for wearing the activPAL was too long. This could hamper student retention, particularly if further assessments are planned beyond pre- and post-test measurements (e.g., follow-up). One option could be reducing the number of wear days per assessment. A recent study showed that activPAL data from five wear days provide precise estimates of weekly activity behaviour in adults, as long as at least one weekend day is included (Aguilar-Farias et al., 2019).

Overall, students gave positive feedback for, and engaged with, the majority of intervention components, except for the smartphone apps list. Given the high levels of smartphone penetration and use among young adults in Australia (Oviedo-Trespalacios et al., 2019), we were surprised that the students did not generally download any of the suggested apps to facilitate sedentary behaviour change. It is likely that the apps were not used because students were already receiving automatic reminders and information regarding sedentary behaviour via text messages, which is similar to what most freely available apps targeting sedentary behaviour offer (using 'push notifications' instead of text messages). Some students mentioned that they were going to re-examine the apps list once the scheduled text messages stopped, as an alternative way to receive prompts. The use of text messages has proved effective in previous studies targeting health behaviour change in university students and

constitutes a promising, low-cost intervention approach (Head et al., 2013; Obermayer et al., 2004).

An important component of the process evaluation consisted of exploring the intervention's mechanisms of action, based on the BCTs implemented. Relevant mechanisms identified through the interviews, and supported by the results from the mechanism of action questionnaire, included: feedback processes, motivation, intentions, beliefs about consequences, knowledge, behavioural cueing, and attitude towards the behaviour. These mechanisms share common elements, as most of them refer to the 'reflective motivation' and 'psychological capability' constructs within the COM-B model (Michie et al., 2011). That is, the one-on-one session and complementary information appeared to increase awareness of the health consequences of excessive sedentary behaviour, and thus provided motivation for the students to make changes to the amount of time they spend sedentary. In addition, results from the process evaluation showed that automatic mechanisms also play an important role in reducing sedentary behaviour ('automatic motivation' within the COM-B model). The personalised feedback provided on baseline sedentary behaviour (feedback processes) and the regular text-messages (behavioural cueing) were two intervention components that the students identified as most helpful to achieve the desired change. A common element of these two strategies is that they are based on bringing habitual behaviour into conscious awareness. Given that sedentary behaviour is mostly habitual (i.e., it involves little cognitive engagement and is driven by automatic responses), specific strategies targeting unintentional and habit-like behaviour are needed to better control sedentary time (Compernolle et al., 2019). Feedback /monitoring of behaviour and behavioural cueing are thus two useful approaches to disrupt sedentary behaviour and should be considered in future interventions, together with strategies targeting reflective motivation (e.g., information on health effects).

Having a preliminary understanding of how the intervention works is desirable as it can allow a more detailed analysis during subsequent process evaluations. This might involve the use of standardised questionnaires to thoroughly examine the variables of interest, as well as using mediational analysis to test and quantify the proposed indirect effects (e.g., that the intervention influences sedentary behaviour via changes in reflective motivation). In addition, these findings can be

used to further optimise the intervention. For example, while behaviour change did not seem to be enhanced by social support in our intervention, available research indicates that the health choices of adolescents and young adults are greatly influenced by peers (Yeager et al., 2018). Moreover, our sample of students cited social norms to sit as a barrier to reduce and break up their sedentary behaviour, similar to previous studies with office workers (Mansfield et al., 2018). Based on the above, decisions should be made as to whether to modify or introduce new elements in the intervention to address social support/social norms more directly. For example, this could be done by delivering part of the intervention through group sessions, setting up 'active' study groups or a buddy system.

By using the NWU questionnaire, we were able to better understand how the participants spent their sedentary time during the trial period. The dominant sedentary behaviour subdomains in our sample were screen time and academic activities. This is consistent with the results from our recent meta-analysis (Castro et al., 2020a) and suggests that future interventions targeting sedentary behaviour reduction in university students should pay close attention to these two behavioural contexts. Because different sedentary behaviours might be influenced by different factors, targeting specific subdomains or contexts might help intervention developers to identify more precisely what the sources of implementation problems are, thus increasing the likelihood for the intervention to be effective (Michie et al., 2008).

Last, an important element of our intervention consisted of arranging an individual session between the participant and the researcher, where most of the BCTs forming the intervention were delivered. We based this decision on previous studies that provide support for the efficacy of an individual face-to-face intervention session in reducing sedentary behaviour in older adults (Fitzsimons et al., 2013; Gardiner et al., 2011). However, it is worth noting that the sessions could be adapted to a group format, which should facilitate the intervention's scalability as well as reinforce the social elements that are judged as relevant to change sedentary behaviour (e.g., promote social acceptability for standing and breaking up sitting time). In addition, we believe that it is important to include a combination of self-reported and device-based data to evaluate future intervention, as both assessment methods present unique advantages. If this is not feasible in a large-scale trial (e.g., due to lack of enough accelerometers), using device-based measures only for a

subsample of participants might be a good compromise, to serve as validation for the self-reported results.

Study strengths and limitations

Strengths of this study include the focus on university students (an understudied population subgroup in regards to sedentary behaviour change), the use of an evidence- and theory-based framework to develop the intervention, the incorporation of a process evaluation informed by the MRC guidelines, and the assessment of sedentary behaviour by both accelerometer and self-report methods. Limitations are the lack of control condition, the small sample size, and the short-term duration of the study. Although the purpose of the study was to conduct a feasibility investigation (not a thorough evaluation of the intervention's effectiveness), a larger sample size was initially planned, including a control group and an additional follow-up assessment. However, we had to suspend the students' recruitment due to the Covid-19 restrictions. For future research evaluating effectiveness, an adequately powered sample of participants with one or more follow-up assessments are needed to ascertain the reliability and sustainability of the behavioural changes observed. In addition, adding a control condition is particularly important, because the students identified several environmental factors influencing their sedentary behaviour patterns over time (e.g., weather, university workload).

Conclusions

Our findings suggest that a brief, BCW-informed intervention (composed of a single one-on-one session and automated daily text messages) may help university students to reduce sedentary behaviour and enhance movement during weekend days. Based on the process evaluation results, we propose that the intervention effects occurred through changes in the student's reflective motivation and psychological capability regarding sedentary behaviour. We discuss different strategies that could be added to the current intervention to maximise its potential for reducing and breaking up sedentary behaviour, such as establishing a collaboration with university staff, introducing sit-to-stand desks, and/or facilitating social support. Overall, the intervention's implementation and evaluation were feasible and acceptable to the students. A larger, randomized controlled trial with follow-up assessments is warranted to appropriately evaluate intervention effectiveness.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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Table 1. Behavioural diagnosis for target behaviour 'reducing and breaking up sedentary time', along with intervention functions, behaviour change techniques, intervention strategies, and mechanisms of action.

Behavioural diagnosis using TDF domains linking to COM-B components – What needs to change?	Intervention functions[a]	Behaviour Change techniques (BCT v1)[b]	Intervention strategies employed (BCT implementation)	Potential mechanisms of action[c]
Psychological capability				
Knowledge - Know that accumulating high levels of sedentary behaviour has negative physical and mental consequences, and that prolonged sedentary time is particularly detrimental to health. - Know when and for how long break up sedentary time, including which activities constitute an effective break from sitting	Education, training	Information about health consequences, information about social and environmental consequences, instruction on how to perform a behaviour	- Raising awareness about the risks of sedentary behaviour through infographics and copies of public health guidelines - Provide instructions on break frequency and duration, including strategies to break up sedentary behaviour	Knowledge, attitude towards the behaviour, belief about consequences, intentions

Memory, attention and decision processes - Notice and remember to reduce and break up sedentary behaviour	Enablement, Environmental restructuring	Self-monitoring of behaviour, adding objects to the environment, prompts/cues	- Prompt the participant to identify and reduce 'mindless sedentary behaviour'. This is, daily activities that could be easily done standing or walking, but that are undertaken in a sitting position as this is the default position (e.g., waiting in the bus stop) - Instruct the participants to set an alarm for every 30 minutes or employ other similar strategies to break up sedentary behaviour (e.g., use playlists with a set duration, use of activity trackers) - Send daily reminders to break up and reduce sedentary behaviour via automated text messages - Provide visual cues (posters) reminding participants to reduce and to break up their sedentary behaviour	Behavioural regulation, behavioural cueing

Behavioural regulation - Set specific goals in relation to reducing and breaking up sedentary behaviour - Establish a method to monitor sedentary behaviour	Education, training, enablement	Self-monitoring of behaviour, feedback on behaviour, goal setting (behaviour), action planning	- Set SMART goals to reduce and break up sedentary behaviour - Provide the participant with individually tailored feedback on sedentary time in order to guide goal-setting - Encourage self-monitoring of behaviour by using a smartphone, a tracking device or a workbook with daily checklists - Use action planning to specify when, where, and how participants will reduce and break up sedentary behaviour (implementation intentions) - Provide generic tips to reduce and break up sedentary behaviour and invite participants to identify strategies specific to their circumstances	Goals, behavioural regulation, motivation, feedback processes, skills
Reflective motivation				

Beliefs about consequences - Reinforce the physical and mental health benefits from reducing and breaking up sedentary behaviour - Challenge the perception that reducing and breaking up sedentary behaviour during private academic activities will disturb the student's work and concentration Intentions - Develop intentions to reduce and break up sedentary behaviour during private academic activities	Education, persuasion	Information about health consequences, information about social and environmental consequences, credible source, framing/reframing, instruction on how to perform the behaviour, social comparison	- Present data supporting the idea that reducing and breaking up sedentary behaviour has a positive impact on health, as well as on cognitive processes related to academic performance (e.g., attention levels, mental fatigue) - Suggest that the participant might think of taking short breaks as a way to 'refresh' his attention and improve performance (rather than procrastination) - Provide guidance on how to work efficiently while reducing and breaking up sedentary behaviour (e.g., highlight tasks that can be undertaken standing up, or recommend strategies to assist the students in getting back to their work quickly after the break) - Raise awareness about the fact that university students typically show higher levels of sedentary behaviour compared to the general population and thus should pay special attention to their sedentary behaviour patterns	Knowledge, attitude towards the behaviour, belief about consequences, intentions, skills, social/professional role and identity

Automatic motivation				
Reinforcement - Establish routines and habits to break up sedentary behaviour	Environmental restructuring, training, incentivisation	Habit formation, behavioural practice / rehearsal, self-monitoring of behaviour, self-reward	- Prompt rehearsal and repetition of the target behaviour in the same context repeatedly so that the context elicits the behaviour (e.g., suggest the participant to consistently break up sitting while studying in his room, or stand up while having coffee every morning) - Prompt self-reward if there has been progress in reducing and breaking up sedentary behaviour	Behavioural cueing, reinforcement
Social opportunity				

Social influences - Promote social acceptability for reducing and breaking up sedentary behaviour	Environmental restructuring, restriction	Social support (unspecified), information about others' approval, identification of self as role model	- Inform the participant that other students approve and encourage reducing sitting and taking breaks (motivational quotes from other students) - Encourage the participant to involve other students when reducing and breaking up sedentary behaviour and 'spread the message' - Suggest that the participant's own behaviour may be an example for other students to reduce and break up their sedentary behaviour	Subjective norms, social influences, self-image

[a]The Behaviour Change Wheel describes nine potential intervention functions. This is, broad categories of means by which an intervention can change behaviour, including education, training, persuasion, incentivization, coercion, restriction, modelling, environmental restructuring, and enablement (Michie et al., 2014).

[b]A Behaviour Change Technique (BCT) is an 'active ingredient' of change and is defined as an "observable, replicable, and irreducible component of an intervention designed to alter or redirect causal processes that regulate behaviour" (Michie et al., 2014). The Behaviour Change Technique Taxonomy version 1 (BCTTv1) includes 93 BCTs grouped within 16 categories and can provide a greater level of intervention detail for synthesis, comparison, and replication of studies.

[c]The Theory & Technique Tool specifies 26 different mechanisms of action, defined as processes through which behaviour change occurs (Michie et al., 2018).

Table 2. Characteristics of participants in the pilot trial and process evaluation (n = 9).

Variables	**% (n), Mean ± SD**
Gender (females)	56% (5)
Age	22 ± 2.32
Year of undergraduate study	
1st year	22% (2)
2nd year	33% (3)
3rd year	45% (4)
Major subject of study	
Business economics	11% (1)
Finance	22% (2)
Law	22% (2)
Primary education	11% (1)
Mixed courses (e.g., finance and accounting)	33% (3)
Race/Ethnicity	
White	89% (8)
Pacific Islander	11% (1)
Employment status	
Student (only)	67% (6)
Student with part-time job	33% (3)
Residency	
On-campus	11% (1)
Off-campus	89% (8)

Table 3. Descriptive statistics and pre-post comparison (paired t-tests) for the activPAL outcomes (n = 9).

Variables	**Pre**[a]	**Post**[a]	**Mean difference**	**p-value**[b]	**Effect size**[c]
Total					
Sitting time	10.62 (0.99)	10.17 (1.35)	-0.45	0.12	-0.58
Standing time	3.10 (0.77)	3.38 (1.20)	0.28	0.22	0.44
Stepping time	1.49 (0.36)	1.66 (0.4)	0.17	0.125	0.57
Time in sitting bouts >30 min	6.58 (1.64)	6.10 (2.08)	-0.48	0.285	-0.38
Time in sitting bouts >60 min	3.50 (1.38)	3.00 (1.7)	-0.50	0.274	-0.39
Sit-to-stand transitions	42.79 (9.20)	43.27 (8.28)	0.48	0.863	0.05
Step count	6962.4 (1898.89)	7615.92 (2173.10)	653.51	0.189	0.47
Weekdays					
Sitting time	10.39 (0.93)	10.55 (1.45)	0.15	0.722	0.12
Standing time	3.2 (0.7)	3.09 (1.26)	-0.11	0.734	-0.11
Stepping time	1.61 (0.42)	1.57 (0.46)	-0.03	0.82	-0.07
Time in sitting bouts >30 min	6.26 (1.74)	6.38 (2.15)	0.13	0.855	0.06
Time in sitting bouts >60 min	3.13 (1.15)	3.39 (1.61)	0.26	0.659	0.15
Sit-to-stand transitions	43.38 (10.69)	46.08 (9.97)	2.69	0.517	0.22
Step count	7693.38 (2258.18)	7374.66 (2401.63)	-318.72	0.618	-0.17

Weekend					
Sitting time	11.06 (1.6)	9.41 (1.99)	-1.65	**0.005**	-1.27
Standing time	2.86 (1.36)	3.96 (1.71)	1.10	**0.019**	0.97
Stepping time	1.28 (0.33)	1.83 (0.51)	0.55	**0.003**	1.44
Time in sitting bouts >30 min	7.2 (2.1)	5.55 (2.66)	-1.65	**0.007**	-1.18
Time in sitting bouts >60 min	4.25 (2.36)	2.22 (2.12)	-2.03	**0.002**	-1.44
Sit-to-stand transitions	41.72 (7.67)	37.66 (9.93)	-4.05	0.092	-0.63
Step count	5585.11 (1554.06)	8098.44 (2529.31)	2513.33	**0.004**	1.32

[a]Mean hours/steps per day (standard deviation)

[b]Bold text indicates $p < 0.05$ for paired t-test.

[c]Effect size = Hedges' g (Grissom & Kim, 2005).

Table 4. Descriptive statistics and pre-post comparison (related samples Wilcoxon Signed Rank Test) for each of the Nightly-Week-U dimensions (n = 9).

Variables	**Pre**[a]	**Post**[a]	**Median difference**	**p-value**[b]	**Effect size**[c]
Total (6 days)					
Sitting time	10.31 (2.14)	9.01 (2.06)	-1.30	**0.021**	-0.54
Sitting for study	1.81 (1.62)	2.30 (2.17)	0.49	0.678	-0.10
Sitting for work	0.21 (0.89)	0.25 (0.53)	0.04	0.345	0.22
Sitting for transport	0.73 (0.5)	0.74 (0.7)	0.01	0.953	0.01
TV viewing	0.81 (2.31)	0.50 (1.79)	-0.31	0.401	-0.20
Computer use	1.86 (1.53)	1.73 (2.45)	-0.13	0.767	-0.07
Sitting for leisure reading	0.04 (0.34)	0 (0.56)	-0.04	0.917	-0.02
Sitting for eating	1.15 (0.79)	0.78 (0.61)	-0.38	0.441	-0.18
Sitting for socialising	0.8 (0.95)	0.78 (1.14)	-0.02	0.484	-0.16
Sitting for other purposes	1.14 (1.23)	1.10 (0.74)	-0.04	0.214	-0.29
Weekdays					
Sitting time	10.14 (1.97)	9.13 (2.19)	-1.01	0.139	-0.35
Sitting for study	1.73 (1.75)	3.10 (2.16)	1.37	**0.028**	0.52
Sitting for work	0.14 (1.34)	0.16 (0.43)	0.02	0.345	0.22
Sitting for transport	0.75 (0.63)	0.38 (0.86)	-0.37	0.953	-0.01
TV viewing	1.21 (2.31)	0.23 (1.81)	-0.98	0.176	-0.32
Computer use	2.09 (1.34)	1.20 (1.94)	-0.89	0.109	-0.38
Sitting for leisure reading	0.06 (0.39)	0 (0.12)	-0.06	0.345	-0.22

Sitting for eating	1.15 (0.65)	0.71 (0.76)	-0.44	0.314	-0.24
Sitting for socialising	0.85 (1.41)	0.34 (1.56)	-0.5	0.779	-0.07
Sitting for other purposes	0.68 (1.76)	0.81 (1.18)	0.12	0.678	0.1
Weekend					
Sitting time	10.69 (3.25)	8.76 (4.48)	-1.92	**0.021**	-0.54
Sitting for study	1.52 (3.3)	1.41 (2.61)	-0.11	0.401	-0.2
Sitting for work	0 (0.37)	0 (0.66)	0	1.000	0
Sitting for transport	0.52 (0.37)	0.7 (0.9)	0.17	0.594	0.13
TV viewing	0.51 (2.68)	1.05 (2.21)	0.54	0.889	0.03
Computer use	2.06 (3.04)	1.45 (2.16)	-0.62	0.515	-0.15
Sitting for leisure reading	0 (0.21)	0 (0.46)	0	1.000	0.00
Sitting for eating	1.04 (1.11)	0.87 (0.34)	-0.18	0.214	-0.29
Sitting for socialising	1.17 (1.76)	0.78 (1.34)	-0.39	0.499	-0.16
Sitting for other purposes	1.55 (2.43)	1.39 (1.67)	-0.17	0.263	-0.26

[a]Median hours/steps per day (interquartile range)

[b]Bold text indicates $p < 0.05$ for related samples Wilcoxon Signed Rank Test.

[c]Effect size = Rank-biserial correlation (Rosenthal, 1994).

Table 5. Themes elicited from process evaluation interviews with university students (n=9).

Themes	Category	Subcategory	Exemplar statement	Frequency across interviews (n=9)
Implementation	Assessment	Wearing the activPAL was comfortable	*"It didn't bother me at all. After a few hours you just forget it is there."*	8
		Data collection reminders via text messages were helpful	*"The reminder to collect the data at the end of the day was really good, just to remember about it."*	7
		Too many wear days (activPAL)	*"Towards the end of the second week I got a bit fed up, especially at night, as I sleep face down."*	2
	Intervention	The intervention session was helpful and clearly delivered.	*"I think everything was really clear. I liked the visuals, that really helped me, and also the definitions for different physical activities. It was very informative and it made me think a lot about how much sitting really affects me."*	8
		I didn't use any of the apps suggested	*"I did look at the apps, I just didn't get around to using them myself."*	8

		The intervention text messages were helpful	*"I thought the text messages were really great. With some of the apps I've tried, they were just like 'get up and get a drink of water now, bla bla bla'. But with the text messages I thought that was better for me because there were reasons, suggestions, etc all different types of reminders, more complex."*	7
		Poster was an effective visual cue	*"I had the poster on my desk and when I was studying I looked at it and I was like 'think outside the chair'* (poster phrase)*, that was really good, as a cue."*	4
		The intervention text messages were irrelevant	*"It wasn't helpful for me personally. I'm not on my phone, I don't keep my phone with me that much. Most people are attached to their phones. I'm not one of them."*	2
Context	University workload	Higher levels of total and prolonged sedentary behaviour during the exam period	*"Towards the end of the semester, when I start doing exam revision, I probably sit down more to focus, because I can't… otherwise my mind wanders a bit too much. So, yes, the closer to exam time, I probably sit a lot longer."*	8
	External influences during the study period	Pre and post periods were comparable	*"In general yes. That was the only out of the norm thing. But generally my routine didn't change at all, so I studied the same, worked the same, etc."*	8

	Weather	Higher levels of total and prolonged sedentary behaviour during winter/summer	*"In winter, when it's cold, I'm more likely to grab a blanket and wrap up. In summer, I'd be sitting down as well, because it's too hot to do anything. So the weather does affect me."*	5
	Work	Higher levels of total and prolonged sedentary behaviour during days off	*"For me, because I do work, I do stand a lot when I work. Then I'd tend to sit a lot when I'm at home. I just sit a lot."*	2
Mechanisms of action	Knowledge	Increased knowledge about sedentary behaviour	*"It has influenced me yes. What I've learnt about sitting behaviour, and why it matters. I think the access to the information that you gave me has definitely opened up my mind."*	8
	Attitude towards the behaviour	Negative attitude towards *too much* sitting	*"Yeah, definitely. As I said, the other day I just got fed up seeing how much I was actually sitting down. I got sick and tired of watching TV every day. And I'm like 'no, get out'."*	7
		Sedentary behaviour is not inherently bad	*"I didn't really see it… I don't have a negative attitude towards too much sitting. It can help me to get my degree, for example."*	2
	Feedback processes	Feedback was eye-opening	*"I was just shocked by that day I spent 20 hours sitting. I think seeing the data there really was like 'okay, that's just the facts, I have to change it, I can't argue it'. It definitely did motivate me."*	8

Motivation	Increased motivation	*"I feel I'm more motivated, not just for* (reducing) *sitting but also to be more active in general, like walking more. I catch an Uber for everything…"*	7
Belief about consequences	Reducing total and prolonged sedentary behaviour is good for your physical health	*"I think even… I've had a lot of back pain in the past, and that has felt better this week because I've gone out walking, I've spent more time standing up."*	8
	Reducing total and prolonged sedentary behaviour is good for your mental health	*"For me it was definitely the mental aspect. It kind of refreshes you. If you do something for too long and then once you stand up, I feel it kind of refreshes my mind a little."*	6
	Breaking up sedentary behaviour helps you to be more organised	*"It has helped me to organise my time more efficiently, by breaking up my day. Usually I'm so disorganised."*	2
Behavioural cueing	Text messages as effective prompts/cues	*"One of the really good things were the text messages, as a reminders. It helped me, I think if I didn't have it would have been a lot harder* (change behaviour)*."*	7
	Visual cues as effective triggers	*"Looking at the poster was a good reminder, especially when I was tired and started looking away from the screen."*	*4*
Intentions	Conscious decision to reduce total and prolonged sedentary behaviour	*"I feel I was thinking about it a lot this week. Before I was not actively trying to make changes in this area, I'd be mindlessly sitting."*	6

Behavioural regulation	Goals to reduce total and prolonged sedentary behaviour	*"One of my goals was to go for a walk and one was to do the dishes, and that sort of thing… so having goals was good. I'm a bit of an achievement-hunter, so I really wanted to achieve the goal. I think that was really helpful."*	4
	Self-monitoring of sedentary behaviour	*"I kind of tracked my behaviour when I was studying, with the computer clock. For example, 'I wanna do three hours and I divide it in blocks of 30-45 minutes'."*	5
Skills	Develop new skills	*"Yes, I've developed new skills, based on some of the strategies we discussed to reduce and break up my sitting time."*	5
	Use existing skills	*"I'd say no. Because I wasn't doing things that I was not doing before, but just maybe more often."*	4
Social/professional role and identity	Part of the student role	*"Yes, cause it's mainly when I'm more conscious of breaking up my sitting, when I'm studying."*	5
	Not part of the student role	*"A little bit. I don't see it as a huge part of my student role. Studying, completing assignments, absolutely, but this one, not sure…"*	4
Reinforcement	I don't bribe myself	*"I don't know. I didn't really use prizes or anything like that."*	7

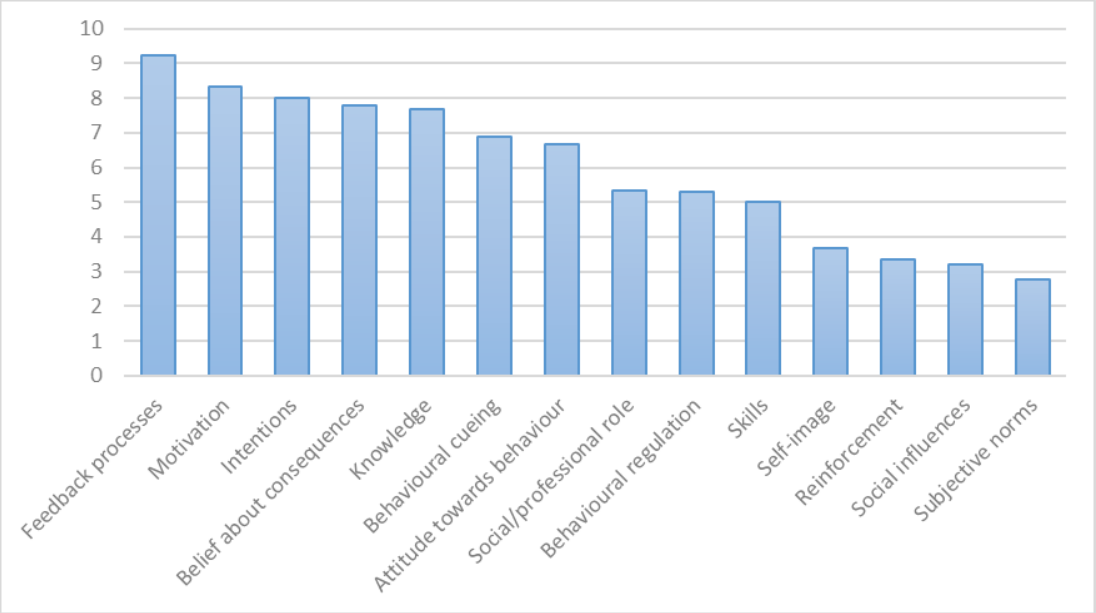
	Use of snack breaks	*"I guess I could call it… when I have a break to stand up I'm having a snack, and drink water or* (have) *something to eat."*	2
Subjective norms	Reducing and breaking up sedentary behaviour is not emphasised in the university setting	*"Not really, I definitely don't think it's even acknowledged at the uni. There's no real focus on activity in the courses I'm in, or any of the people I do the course with. There is not a focus into a healthy lifestyle."*	8
Social influences	No external influences	*"Not really. It was my individual behaviour. My parents were aware I was participating in the study, but they didn't influence me."*	7
	I've tried to convince others to reduce their sedentary behaviour	*"I haven't had a lot of social support… it was more me trying to help him* (partner)*."*	5
	Family members promote change	*"Yes, my dad, he nudges, he's like 'get up, do this, do that', so I think one of the days I was just sitting down reading and he came and annoyed me to go and tidy up the yard, so he pretty much bugged me to get up. They knew I was going to do this as well* (participating in the study)*."*	2
Self-image	Not long enough to change one's conception of oneself	*"Not so much in a week. If I continue over a month or so I'll definitely… I feel I've been standing a fair bit more though."*	8

Behaviour change process	Strategies	Perform tasks standing or moving rather than sitting	*"The activities I could do standing, I just did it, like talking on the phone or something like that."*	7
		More household jobs	*"Yeah, doing a lot more households jobs. I was more motivated to break up sitting by doing something else in between sitting, like study for a little bit and then get up, fold the washing, or actually cook a meal or something like that, and then go and sit down."*	4
		Use of visual cues	*"I put sticky notes on my laptop to just remind me to break up sitting. I think I'm probably more like a visual person."*	4
		Take the long way	*"I did the 'take the long way' thing* (suggested strategy)*, for example this morning I took a diversion to come here and meet you, to make it longer."*	3
	Barriers	Easy to forget about it	*"I'm like one person that when I'm studying I kind of forget* (to reduce and break up sitting)*, or if I'm on my phone… I just don't see the time."*	7
		Goal conflict with studying	*"It was hard to maintain* (behaviour change)*, with external factors like studying, classes, etc."*	5

	Social norm to sit	*"My family came, so I sat a lot for socialising. I didn't want to be rude and just stand up during the conversation. That was another factor, just being with your friends or family… 'oh I need to stand up', and they say 'why are you standing up? Are you okay?'."*	3
	Difficult to 'break' a habit	*"Nothing preventing me* (from reducing and breaking up sedentary behaviour), *just the habit I guess. It's hard after only six days. I think it takes a little bit longer to create a habit, so if it was a bit more prolonged I definitely think you see more changes in my patterns."*	2
How sedentary behaviour was substituted	A combination of standing and walking	*"I did go for a few more walks this week, but yeah, when I had the breaks I was mostly standing, not really walking that much."*	3
	Mainly walking	*"When I wasn't sitting I was probably just walking around, maybe do something in the house like clean up or stuff like that."*	3
	Mainly standing	*"I was replacing it* (sitting) *mainly with standing. The activities I could do standing, I just did it. I tried studying while standing a little bit as well."*	3

Occupational vs non-occupational	Recreational easier	*"Recreational is easier, because if I'm listening to a lecture I kind of have to sit there and listen to it. With leisure activities I can make choices* (to reduce and break up sitting). *For example, going for a walk with friends."*	7
	Studying easier	*"Studying was easier, because I had the timer. 'Times is up, time to move away', as opposed to looking at something else. Because I'm not really thinking about sitting when I'm watching TV. I didn't make a conscious effort to get up."*	1
Future behaviour	I'll continue reducing and breaking up my sedentary time	*"I'm going to take what I've learnt from this, cause really it's not that hard just to stand when you don't have to be sitting. So I think I'll continue and find more ways to reduce my sitting in total."*	9

Figure 1. Mean score for the 14 mechanisms of action statements explored in the process evaluation interviews with university students (n = 9).



Feedback processes: Processes through which current behaviour is compared against a particular standard. **Motivation**: Processes relating to the impetus that gives purpose or direction to behaviour and operates at a conscious or unconscious level. **Intentions**: A conscious decision to perform a behaviour or a resolve to act in a certain way. **Belief about consequences**: Beliefs about the consequences of a behaviour (i.e., perceptions about what will be achieved and/or lost by undertaking a behaviour, as well as the probability that a behaviour will lead to a specific outcome). **Knowledge**: An awareness of the existence of something. **Behavioural cueing**: Processes by which behaviour is triggered from either the external environment, the performance of another behaviour, or from ideas appearing in consciousness. **Attitude towards the behaviour**: The general evaluations of the behaviour on a scale ranging from negative to positive. **Social/professional role and identity**: A coherent set of behaviours and displayed personal qualities of an individual in a social or work setting. **Behavioural regulation**: Behavioural, cognitive, and/or emotional skills for managing or changing behaviour. **Skills**: An ability or proficiency acquired through practice. **Self-image**: One's conception and evaluation of oneself, including psychological and physical characteristics, qualities, and skills. **Reinforcement**: Processes by which the frequency or probability of a response is increased through a dependent relationship or contingency with a

stimulus or circumstance. **Social influences**: Those interpersonal processes that can cause oneself to change one's thoughts, feelings, or behaviours. **Subjective norms**: One's perceptions of what most other people within a social group believe and do.

3.3 How the Publication Contributes to the Advancement of the Research Area

There is a paucity of studies exploring ways to reduce sedentary behaviour in university students and the majority of them lack a theoretical basis. Study 4 contributed to this research gap by investigating the feasibility and preliminary effects of an intervention developed in line with the BCW framework and findings from preliminary research. The integration of the outcome and process evaluations on the same study allowed the research team to better understand the intervention's mechanisms of action and develop novel insights on what strategies are more effective to achieve sedentary behaviour change. Recommendations for future intervention development and testing specific to university students were discussed accordingly.

Chapter 4 General Discussion & Conclusion

4.1 Overview of the Chapter

This final chapter provides an overall discussion of the entire program of research, including an overview of the findings, implications, strengths/limitations of the PhD, recommendations for future research, and conclusions.

4.2 Summary of the Aims and Main Findings

The primary aim of this PhD project was to develop and pilot an intervention aimed at reducing and breaking up sedentary behaviour in university students using the Behaviour Change Wheel, a theory-driven intervention development framework. To meet this aim, four studies were undertaken using a variety of study designs that featured a range of quantitative and qualitative analytical techniques.

Study 1 involved carrying out a systematic review exploring the correlates of sedentary behaviour in university students. The majority of correlates found in the literature were non-modifiable variables (e.g., gender). While these may assist in determining the subgroups at risk of being sedentary, a greater understanding of modifiable correlates is needed to identify variables that can be targeted in behaviour change interventions. In Study 2, a meta-analysis approach was used to synthesise the evidence on the levels of sedentary behaviour in university students. Results reinforced the rationale for interventions targeting sedentary behaviour reductions for this particular population subgroup, as findings suggested that university students are highly sedentary (compared to different estimates from the general population). However, similar to Study 1, it was not possible to identify modifiable factors that could explain variation in sedentary behaviour across the included studies. To bridge this identified gap in the literature and inform intervention content, Study 3 explored the factors influencing prolonged sedentary time in university students, using the COM-B model and associated TDF to qualitatively interpret the findings. The students revealed a wide range of beliefs likely to influence their sedentary behaviour patterns. By using the BCW, it was possible to generate likely intervention strategies directly from these beliefs.

The next phase consisted of merging the results from Study 3 with wider relevant literature on sedentary behaviour (i.e., qualitative and interventional

studies), to identify what factors need to change for the students to reduce and break up their sedentary time. Key factors to target included knowledge (i.e., know that accumulating high levels of total and prolonged sedentary behaviour has negative physical and mental consequences), memory/attention processes (i.e., notice and remember to reduce and break up sedentary behaviour), and behavioural regulation (i.e., monitor and regulate sedentary behaviour). Using the results from this 'behavioural diagnosis', the BCW (based on a synthesis of existing intervention development frameworks, Carey et al., 2019, and a consensus exercise by a group of behavioural experts, Connell et al., 2019) provides guidance on which intervention functions and associated BCTs are expected to bring about change (Figure 5). Once the intervention content was developed, further decisions were made regarding the intervention delivery, including key characteristics such as duration, intensity, or mode of delivery. To determine the most suitable mode of implementation for the intervention, the BCW prompts the use of the APEASE criteria – Affordability, Practicability, Effectiveness/cost, Acceptability, Side-effects/safety, and Equity (Michie et al., 2014). These criteria were considered concurrently with evidence gathered from previous intervention studies targeting sedentary behaviour in university students (e.g., Cotten and Prapavessis (2016) study, where authors implemented a text message-based intervention and reported a significant reduction in the students' sedentary behaviour).

Lastly, Study 4 involved conducting a pilot trial and process evaluation to explore the intervention's feasibility and preliminary short-terms effects. Overall, both the intervention protocol (consisting of a one-on-one session and automated daily text messages) and the assessment tools appeared to be feasible and acceptable for the students. Moreover, results suggested the intervention might assist university students in reducing sedentary behaviour and increasing movement, albeit effects were limited to weekend days. Based on the process evaluation findings, different add-on strategies were recommended to further develop the intervention and increase its effectiveness.

4.3 Implications, and Recommendations for Future Research and Practice

Changing sedentary behaviour is complex because it requires individuals to disrupt a highly prevalent behaviour that occurs in multiple contexts and serves

different functions. While our intervention (Study 4) was somewhat successful in achieving behaviour change in the short-term, most participants found it difficult to reduce and break up their sedentary behaviour when carrying out academic activities. The causes of this were identified as mostly due to a perceived goal conflict between performing such activities and changing sedentary patterns. The concern that reducing and breaking up occupational sitting might compromise productivity or affect mood was already evidenced in our qualitative study (Castro et al., 2020b) and in previous interviews with office workers (Cole et al., 2015). To minimise the students' concerns regarding productivity, we used different strategies in our intervention, such as provide recommendations on how to work efficiently while breaking up sitting or suggest students think of taking short breaks as a way to "refresh" attention. However, it seems these strategies were not enough to help the students overcome this barrier. Thus, we suggest a more complex approach, recruiting key university staff and implementing broader environmental changes, might be necessary to increase the intervention effectiveness specifically for university-related sedentary behaviour during weekdays. Future studies are needed to examine the use of these strategies.

A key environmental strategy used in interventions with office workers is based on the provision of sit-to-stand desks (Gardner et al., 2016; Shrestha et al., 2018). These desks allow individuals to displace large volumes of sitting to standing, while generally causing little to no disruption in productivity and work routines (Karakolis et al., 2014; Smith & Prapavessis, 2017; Ojo et al., 2018). Recent studies have successfully implemented such environmental opportunities in the university setting (Bastien et al., 2018; Jerome et al., 2017), and surveys indicate that a large portion of students believe they should be made available in university classrooms (Smith et al., 2018). Introducing sit-to-stand desks in university classrooms, together with educational/motivational strategies, could be an effective approach to reduce university students' sedentary behaviour. Indeed, a review exploring the effectiveness of interventions to reduce sedentary behaviour in office workers found multi-component interventions to have the greatest sitting reduction, compared to interventions using environmental or educational strategies alone (Chu et al., 2016). Future intervention developers, however, should consider some limitations of standing desks specifically for university students. Unlike most office workers,

students carry out academic activities at different locations (e.g., classroom, library, home), thus providing sit-to-stand desks might have limited influence on their sedentary behaviour patterns. In addition, standing desks are expensive, and it is not clear who will cover their cost in the university setting (for office workers, they are generally provided by the employer). Last, the use of standing desks in university classrooms seems to be greatly influenced by social factors (Jerome et al., 2017), thus students might not use them unless a socially conducive environment is established (e.g., receiving encouragement from the lecturer or seeing other students stand).

Similar to previous interventions with office workers (Munir et al., 2018), the personalised feedback provided on baseline sedentary behaviour and the regular text-messages (prompts) were two intervention components that the students identified as most helpful to achieve the desired change. A common element of these two strategies is that they are based on bringing habitual behaviour into conscious awareness. Given that sedentary behaviour is mostly habitual (i.e., it involves little cognitive engagement and is driven by automatic responses), specific strategies targeting unintentional and habit-like behaviour are needed to better control sedentary time (Compernolle et al., 2019). Monitoring of behaviour and behavioural cueing are thus two useful approaches to disrupt sedentary behaviour and should be considered in future interventions. Moreover, a particularity of these strategies is that they can be easily delivered using technology-enhanced interventions (e.g., apps, wearables). Digital technologies have recently been implemented in healthcare interventions and have the potential to be a high reach, low-cost approach to change behaviour (Cowie et al. 2016). There is promising evidence to support digital technologies as effective intervention tools to reduce sedentary behaviour and increase physical activity (Huang et al., 2019). Last, it should be noted that reflective processes also play an important role in reducing sedentary behaviour and should be considered to inform future interventions. Results from Study 4 showed that changes in the students' sedentary patterns were mediated by increased knowledge of the negative health effects associated with high volumes of sitting.

The systematic literature reviews included in the present thesis evidenced a lack of literature regarding the factors influencing sedentary behaviour in university students. While we have contributed to a better understating of these factors through

our qualitative study, further research relevant to the university setting is needed to address this gap. Quantitative research can also contribute to our understanding of the correlates of sedentary behaviour and assist with the identification of barriers and facilitators to sedentary behaviour change. Emphasis should be placed on university-specific factors (e.g., the major subject of study, year of enrolment), as in most of the available literature students were used as a convenience sample of young adults and sedentary behaviour was not the primary focus of the study. In addition, a comprehensive theoretical framework should be used to provide guidance on what factors can be explored in future studies. For example, the recently developed COM-B questionnaire could be employed to structure the study of correlates and to better understand the key drivers of sedentary behaviour (Keyworth et al., 2020).

The main aim of this thesis was to develop an intervention to both reduce *and* break up sedentary behaviour. That is, we were not only interested in helping students to reduce their overall sedentary behaviour levels but also interrupt long periods of sedentary time more often. While these two behavioural targets are grounded in current public health guidelines (e.g., Australian Department of Health, 2014; UK Department of Health, 2019), some authors have recently questioned the inclusion of sedentary breaks in the evidence-based guidelines, arguing that the studies supporting the beneficial health effects of breaking up sedentary behaviour often present mixed findings and are limited to small samples (Stamatakis et al., 2019). Another disputed topic refers to whether standing is enough to attenuate the negative health effects of total and prolonged sedentary behaviour, as there is only a small difference in energy expenditure between sitting and standing (Bailey & Locke, 2015; Van der Ploeg et al., 2017). While the evidence base is still growing, the answer to these questions might be dependent on the target population, especially concerning people's age, level of physical activity, and presence of chronic conditions (Henson et al., 2016). For example, compared to standing breaks, frequent breaks of light-intensity physical activity have proved to be more effective in rendering favourable metabolic changes for young, physically active adults (Benatti & Ried-Larsen, 2015).

Sedentary behaviour is a relatively new area of research within the physical activity and public health field and, consequently, a number of issues remain to be investigated (Biddle et al., 2019). With research on sedentary behaviour growing

rapidly, researchers and practitioners should pay close attention to the new advancements in the field and tailor their behavioural targets accordingly. As with physical activity guidelines, recommendations on sedentary behaviour are likely to become more sophisticated over time. For example, there are ongoing population studies in the UK (Elliott & Shepherd, 2006) and Norway (Krokstad et al., 2013) that will provide additional insights on the prospective associations of total and prolonged sedentary behaviour with health outcomes, this potentially informing the development of specific, pattern-based public health guidelines for sedentary behaviour. A particular strength of these two ongoing studies is the large sample sizes (e.g., 40,000 – 50,000 adults estimated in the Norwegian sample) and the use of thigh-worn accelerometers.

In light of the current state of the evidence, we grounded our intervention in the message 'sit less, move more, more often', highlighting that standing is a good start, but the additional movement of any intensity will support stronger health effects in university students. Apart from physical health outcomes, however, future intervention developers should also consider the emerging evidence on sedentary behaviour and psychological outcomes (De Cocker et al., 2020). For example, standing seems to play a positive role in increasing alertness and boost productivity (Biddle et al., 2020), which is particularly relevant to university students.

4.4 Strengths and Limitations of the Research

The systematic review, meta-analysis, interviews, and feasibility studies included in this thesis provided a rich source of quantitative and qualitative data. The integration of these methods represents a key strength, as it allowed for a synergistic and thorough utilisation of data. For example, the process evaluation results via one-on-one interviews enabled a deeper understanding of the outcome results from the pilot trial. In addition, another strength of the present thesis is the use of the BCW framework, which does not only incorporate a model of behaviour but also provides intervention designers with a comprehensive and systematic approach on how to select and implement a wide range of theoretical constructs. Using the BCW (including TDF and COM-B components) provided a theory-informed approach to identify determinants of sedentary behaviour (study 3) and a clear rationale for the specific content and design of the intervention (study 4). In addition, the BCT

taxonomy allowed for a detailed report of the intervention content, which is important for replicating and synthesising evidence. Using the shared, standardised vocabulary provided by the BCW, and being explicit about the processes used to develop interventions, will facilitate accumulation and implementation of knowledge.

The use of the activPAL constitutes a major advantage over previous intervention studies in university students, which have mostly relied on self-reports. Self-reports tend to underestimate sedentary behaviour (Chastin et al., 2014) and are highly vulnerable to participant response bias when used in non-blinded interventions (Wilshire, 2014). To the best of our knowledge, Study 4 is the first intervention study targeting university students that uses an accelerometer to examine changes in sedentary patterns. Moreover, the thigh-mounted activPAL is an accelerometer that directly measures postures, which is particularly relevant for sedentary behaviour as the concept includes both postural and energy expenditure elements. Most of the evidence on accelerometer-assessed sedentary time has been derived from measurement devices that infer sedentary behaviour from lack of movement (e.g., arm- or hip-mounted devices). However, this measurement approach might be misleading as all non-stationary activities (including standing) are categorised as sedentary behaviour, regardless of whether they are performed in an upright or seated position (Kim et al., 2015). While accelerometers in general, and the activPAL in particular, are considered the gold standard to assess sedentary behaviour, it should be noted that they do not provide context-specific information on sedentary behaviour patterns. Thus, a combination of both accelerometer-based and self-reported measures is desirable when assessing sedentary behaviour subdomains, or if there is an interest in isolate key periods of interest (e.g., occupational sedentary behaviour).

One potential limitation to this thesis is that participants in Studies 3 and 4 were drawn from the same university, in a single area of the country, potentially limiting the generalisability of results. The views and opinions of these participants may not reflect the perceptions of those in other contexts and caution must be taken when making inferences to students from other universities or geographical areas. This is a general challenge when conducting research with university students, due to the high heterogeneity of the target population with regards to enrolment patterns

(e.g., on-campus vs online), program workload (e.g., undergraduate vs graduate), or the number of classes per semester (full-time vs part-time). We defined our selection criteria to produce findings generalizable to the broader student population (i.e., undergraduate, full-time, on-campus students). Finally, the specific recruitment strategy used involved an active role from the student, who had to contact the research team to participate in the study. Therefore, it is possible that the students who took part were those already engaged or interested in the topic.

Another limitation is that we only considered the students' views when trying to understand the factors influencing sedentary behaviour and inform intervention content. Perhaps a wider participatory approach, including feedback from lecturers and other relevant stakeholders, could have provided a more detailed picture of the behaviour and allowed the research team to be more comprehensive when selecting intervention options. Inputs from both the target group and key stakeholders can significantly contribute to the conceptualisation and development of interventions (Lee et al., 2018), ensuring the best chance of developing effective behaviour change strategies which are tailored to the target population.

4.5 Conclusions

This thesis featured an evidence-based, theory-informed approach to developing and evaluating an intervention to reduce sedentary behaviour. The intervention was designed in a systematic and comprehensive manner, incorporating theoretical and methodological frameworks, evidence from the literature, and perspectives from university students. Findings suggest that the developed intervention is feasible and has the potential to elicit change in sedentary behaviour patterns. However, a larger, randomized controlled trial (including follow-up assessments) is needed to appropriately evaluate intervention effectiveness. In addition, we recommend future use of the intervention be subject to the improvement of the research protocol and additional iterations. Our approach provides a blueprint for others to follow when developing and evaluating sedentary behaviour change interventions with university students, detailing relevant considerations that should be observed by future development teams.

Although university students typically perform activities that require high volumes of sitting, they have received limited attention within the sedentary

behaviour field, with the majority of the existing evidence accumulated on office workers. The different studies included in this thesis have contributed to the literature by providing a greater understanding of the levels of sedentary behaviour in university students, its associated factors, as well as novel insights on how to better reduce sedentary time and enhance movement specific to this population subgroup.

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Appendix A: Online Supplementary Materials Study 1

Supplementary files to study 1 can be found online at https://

doi.org/10.1016/j.ypmed.2018.09.016

Appendix B: Online Supplementary Materials Study 2

Supplementary files to study 2 can be found online at

https://doi.org/10.1007/s11121-020-01093-8

Appendix C: Online Supplementary Materials Study 3

Supplementary files to study 3 can be found online at

https://doi.org/10.1007/s12529-020-09926-0

Appendix D: Online Supplementary Materials Study 4

Supplementary file 1: The Theoretical Domains Framework (v2) with definitions and component constructs (Michie et al., 2014).

Supplementary file 2: Intervention workbook.

Supplementary file 3: Data collection and intervention text messages.

Supplementary file 4: Daily log.

Supplementary file 5: Interview schedule for process evaluation.

Supplementary file 6: Mechanisms of action questionnaire (statements).

Supplementary file 1: The Theoretical Domains Framework (v2) with definitions and component constructs (Michie et al., 2014)

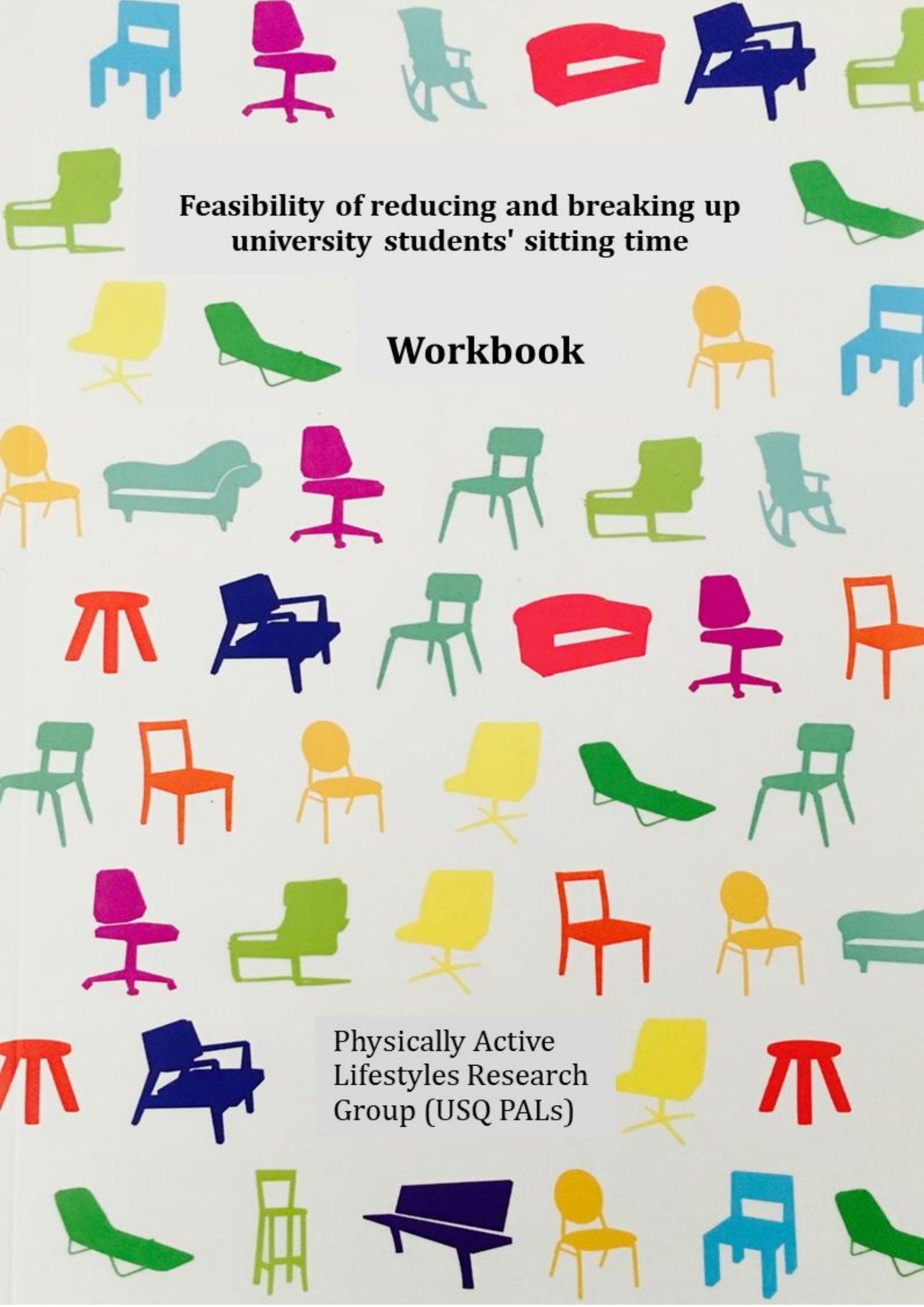
COM-B components	TDF domains linking to COM-B components	Definition	Constructs
Psychological capability	Knowledge	An awareness of the existence of something	Knowledge (including knowledge of condition/scientific rationale) Procedural knowledge Knowledge of task environment
Psychological capability	Memory attention and decision processes	The ability to retain information, focus selectively on aspects of the environment and choose between two or more alternatives	Memory Attention Attention control Decision making Cognitive overload/tiredness
Psychological capability	Behavioural regulation	Anything aimed at managing or changing objectively observed or measured actions	Self-monitoring Breaking habit Action planning
Physiological capability	Skills	An ability or proficiency acquired through practice	Skills Competence/ability/skill assessment Practice/skills development Interpersonal skills Coping strategies
Reflective motivation	Intentions	A conscious decision to perform a behaviour or a resolve to act in a certain way	Stability of intentions Stages of change model Trans theoretical model and stages of change

Reflective motivation	Goals	Mental representations of outcomes or end states that an individual wants to achieve	Goals (distal/proximal) Goal priority Goal/target setting Goals (autonomous/controlled) Action planning Implementation intention
Reflective motivation	Beliefs about consequences	Acceptance of the truth, reality, or validity about outcomes of a behaviour in a given situation	Beliefs Outcome expectancies Characteristics of outcome expectancies Anticipated regret Consequents
Reflective motivation	Optimism	The confidence that things will happen for the best or that desired goals will be attained	Optimism Pessimism Unrealistic optimism Identity
Reflective motivation	Beliefs about capabilities	Acceptance of the truth, reality or validity about an ability, talent or facility that a person can put to constructive use	Self-confidence Perceived competence Self-efficacy Perceived behavioural control Beliefs Self-esteem Empowerment Professional confidence
Reflective motivation	Social / professional role and identity	A coherent set of behaviours and displayed personal qualities of an individual in a social or work setting	Professional identity Professional role Social identity Identity Professional boundaries Professional confidence Group identity Leadership Organisational commitment

Physical opportunity	Environmental context and resources	Any circumstance of a person's situation or environment that discourages or encourages the development of skills and abilities, independence, social competence and adaptive behaviour	Environmental stressors Resources/material resources Organisational culture/climate Salient events/critical incidents Person × environment interaction Barriers and facilitators
Social opportunity	Social influences	Those interpersonal processes that can cause individuals to change their thoughts, feelings, or behaviours	Social pressure Social norms Group conformity Social comparisons Group norms Social support Power Intergroup conflict Alienation Group identity Modelling
Automatic motivation	Emotion	A complex reaction pattern, involving experiential, behavioural, and physiological elements, by which the individual attempts to deal with a personally significant matter or event	Fear Anxiety Affect Stress Depression Positive/negative affect Burn-out

Automatic motivation	Reinforcement	Increasing the probability of a response by arranging a dependent relationship, or contingency, between the response and a given stimulus	Rewards (proximal/distal, valued/not valued, probable/improbable) Incentives Punishment Consequents Reinforcement Contingencies Sanctions

Supplementary file 2: Intervention workbook



Feasibility of reducing and breaking up university students' sitting time

Workbook

Physically Active
Lifestyles Research
Group (USQ PALs)

Authorship

This workbook has been developed by Oscar Castro in collaboration with his supervisory team. Oscar completed his BSc in psychology at the University of Valencia (Spain), and his MSc in sport and exercise psychology at the University of Jyväskylä (Finland). He is currently a PhD researcher in the area of health behaviour change at the USQ Physically Active Lifestyles Research Group (USQ PALs).

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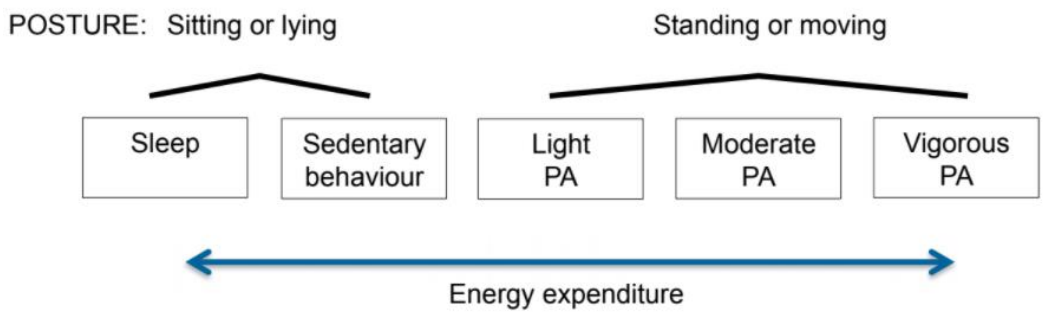
Introduction

What is sedentary behaviour? Waking activities characterized by low energy expenditure and undertaken in a sitting or reclining posture (e.g., reading, watching television, or driving).

SBRN
Sedentary Behaviour Research Network



A depiction of sedentary behaviour and physical activity along an energy expenditure and posture continuum.

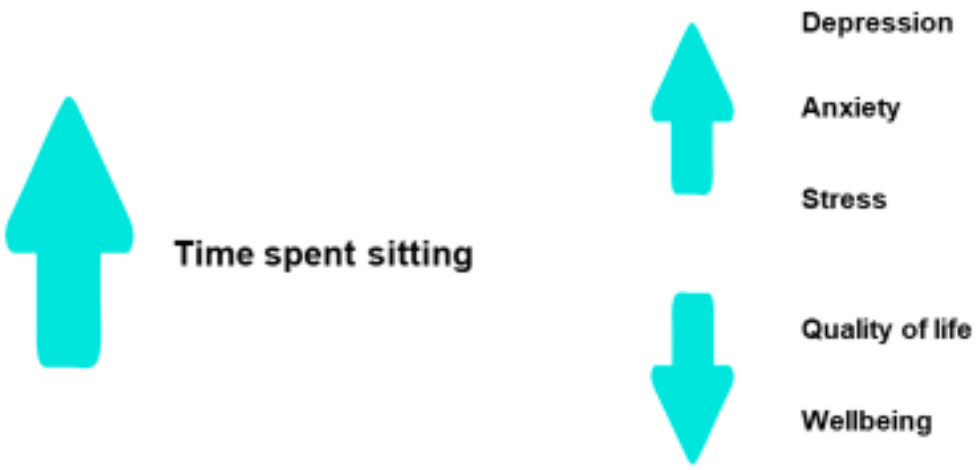
Occupational sitting time

Non-occupational sitting time

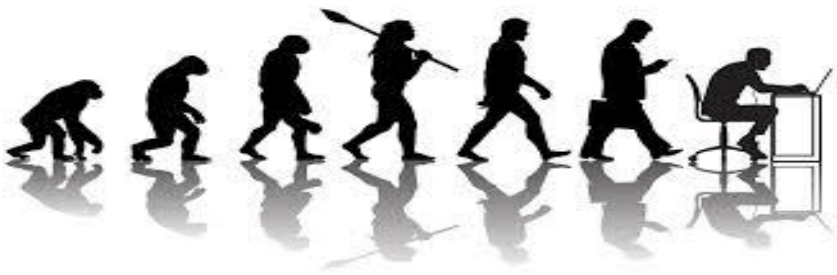
Sitting time and physical health

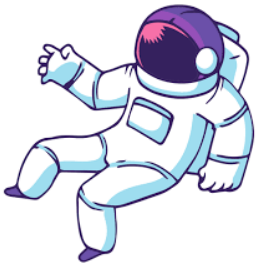
(Cong et al., 2014; Lynch, 2010; Schmid & Leitzmann, 2014; Zhang, Xie, Lee, & Binns, 2004; Edwardson et al., 2012; Greer, Sui, Maslow, Greer, & Blair, 2015; Grøntved & Hu, 2011; Katzmarzyk, Church, Craig, & Bouchard, 2009; Proper, Singh, van Mechelen, & Chinapaw, 2011; Wilmot et al., 2012).

Sitting time and psychological wellbeing

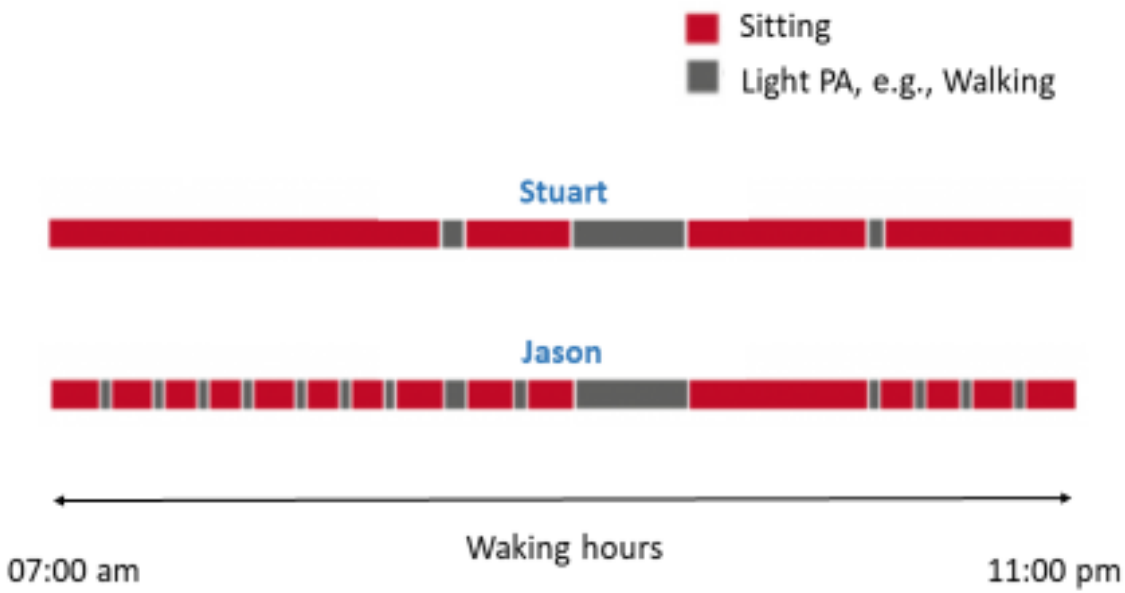


(Hamer, Stamatakis, & Mishra, 2010; Rebar, Vandelanotte, Van Uffelen, Short, & Duncan, 2014; Teychenne, Ball, & Salmon, 2010; Zhai, Zhang, & Zhang, 2014; Rebar et al., 2014; Teychenne, Costigan, & Parker, 2015)





Prolonged sitting time



Prolonged sitting time, health and cognition

(Bellettiere et al., 2019; Benatti & Ried-Larsen, 2015; Diaz et al., 2017; Todd, Bennett, & Chrisitie, 2007; Felez-Nobrega et al., 2018; Cole, Tully, & Cupples, 2015; Wennberg et al., 2016)

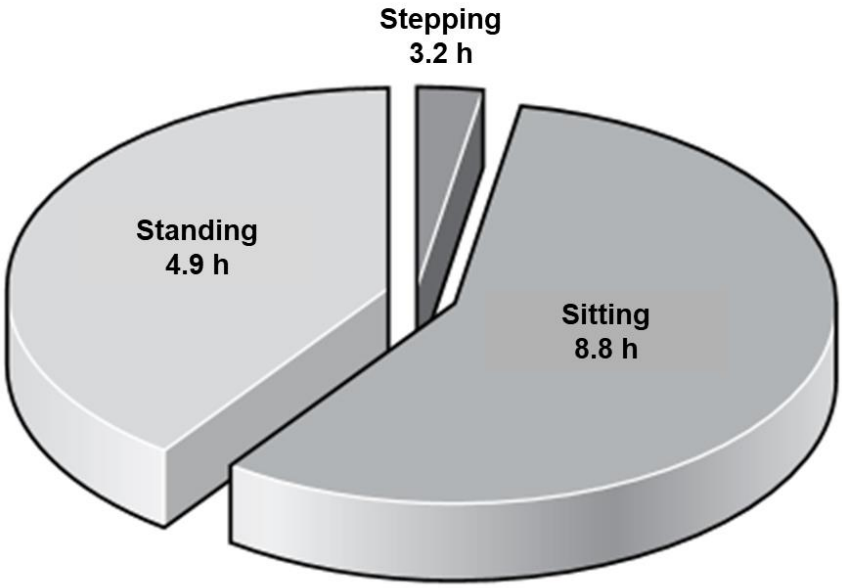
"Sedentary Behaviour Guidelines:
•Minimise the amount of time spent sitting.
•Break up long periods of sitting as often as possible."

(Australian Department of Health, 2014; pag. 35).

Australian Government
Department of Health

The Department of Health

Activity 1: Normative feedback on sitting behaviour



ActivPAL-derived data from a sample of 741 Australian adults (Healy et al., 2015).

Activity 2: Pros and cons

You have had the chance to know more about sitting time and your own sitting behaviour over the past week. How do you feel about it? Are you surprised about the amount of time you spent sitting? Is there something you would like to change?

When we think about making changes, most of us don't really consider all "sides" in a complete way. Instead, we often do what we think we "should" do, avoid doing things we don't feel like doing, or just feel confused or overwhelmed and give up thinking about it at all.

Thinking through the pros and cons of both changing and not making a change is one way to help us make sure we have fully considered all possible options. This exercise will help you look at the good things and less good things about reducing and breaking up your sitting time.

	Benefits/Pros	Costs/Cons
Making a change		
Not changing		

Activity 3: Suggested strategies

If you consider that reducing and breaking up your sitting time might be a good option for you, here is a list of strategies used by other university students:

- **Ask yourself if you actually need to sit.** Much of our sitting is 'mindless sitting' – we don't actually have to be sitting down, we just do it because it's the default position. Look at your day, and see what tasks could just as easily be done standing or walking. For example, talking on the phone or waiting in the bus stop. Some university-related activities, like reading or checking your emails in the phone, can also be undertaken standing up!

- **Try new things.** When it comes to breaking up your sitting time, walking around for a few minutes is always a good choice. However, a wide range of activities can serve for the same purpose, get creative! Skipping, jumping jacks, or even dancing.
- **Take the long way.** If you need to change room between lessons, take a longer route to get to your next class. This can apply to toilet breaks as well. And if the new route includes stairs – even better!
- **Schedule reminders.** Your computer or phone can be valuable allies to remind you about standing and moving. If you listen to music while studying, a playset with a set duration can help too. Some popular physical activity trackers provide tactile feedback after a period of sustained inactivity (Fitbit, Garmin). Similarly, you can use environmental signposting in specific contexts to trigger breaks. For example, placing visuals cues such as posters or post-its in your desk will remind you to move more often (see appendices for some example posters).
- **Set goals**. Health behaviour change is challenging, but there are strategies that individuals can use to facilitate their behaviour change efforts. Goal setting is a self-regulation strategy that assists individuals to identify specific behaviours to change and how to go about doing so (for an example of goal setting, see appendices).
- **Make it social.** If you study with others, you can schedule your movement breaks together. That will make them more enjoyable! If you need to do a group assignment with other students, think about stepping away from the library and scheduling some walking meetings. Not only will this give you the opportunity to get some fresh air, but you'll be able to beat that afternoon slump. Also, if you are in the library and need to talk with other students, walk over to them instead of emailing or texting them.

- **Stay hydrated.** Make regular trips to the kitchen to refill your water glass and add a few steps into your study sessions. Actually, having a coffee or snack break could be a good way to reward yourself and make movement breaks more motivating.
- **Plan in some active time when you are usually sedentary.** In the evenings, consider an exercise class, going for a walk or cooking a healthy meal from scratch. You could even incorporate active time into your commute, parking your car further away or walking part of the journey before you hop on the bus. Home duties and active hobbies such as gardening and DIY are also great options to move more and sit less.
- **Look for opportunities.** Is there any standing desk alternatives available to you? For example, in the library or in some lecture theatres. If so, don't be shy and give it a try; these alternatives can boost your productivity.
- **Get away from the screens.** Most of our interactions with screen devices involve sitting. Look for ways to reduce screen time in your daily life, for example, limiting your time spent surfing the net and social networking. This will not only potentially reduce your sitting time but will also make you feel more connected with your physical and social environment. Getting up in every ad break when watching TV might also be a useful strategy.
- **Listen to your body.** Stand up when you feel tired or uncomfortable.
- Get started with the **Pomodoro technique** while studying (see appendices).

What do you think about these strategies? Are these applicable to you? Feel free to develop your own specific strategies! Be creative, the point is finding effective ways to reduce and break up your sitting time for a better health (Sit less – move more and more often).

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Appendix 1. Goal setting

In order to reduce and/or break up my sitting time in the following week (including occupation and non-occupational sitting), I will try to:

1. *Reduce my sitting time during leisure activities by 1 hour each day.*

When will you do it?

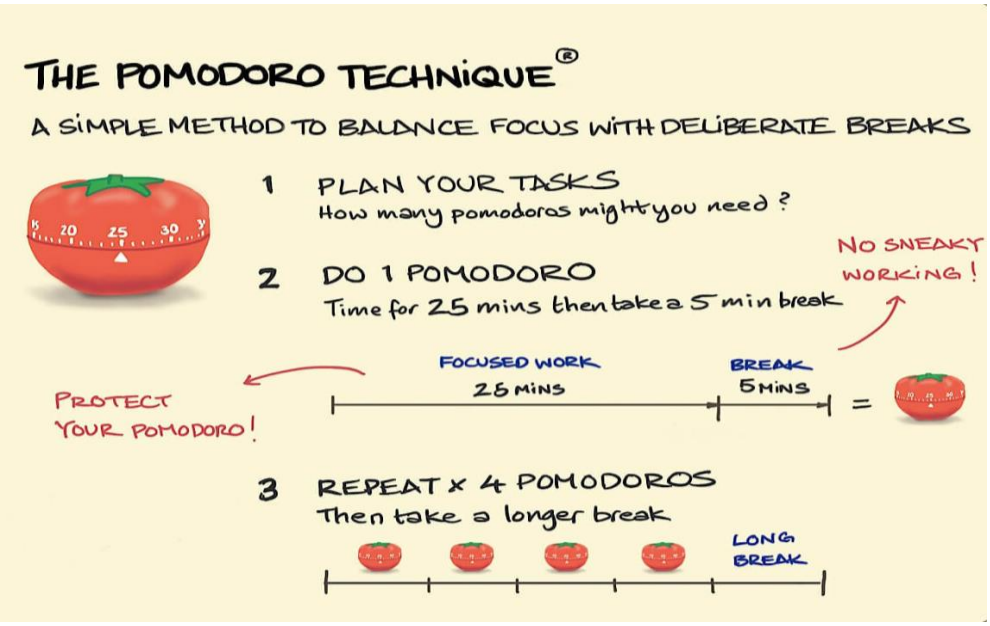
1. *In the evening, right after coming back home from the uni.*

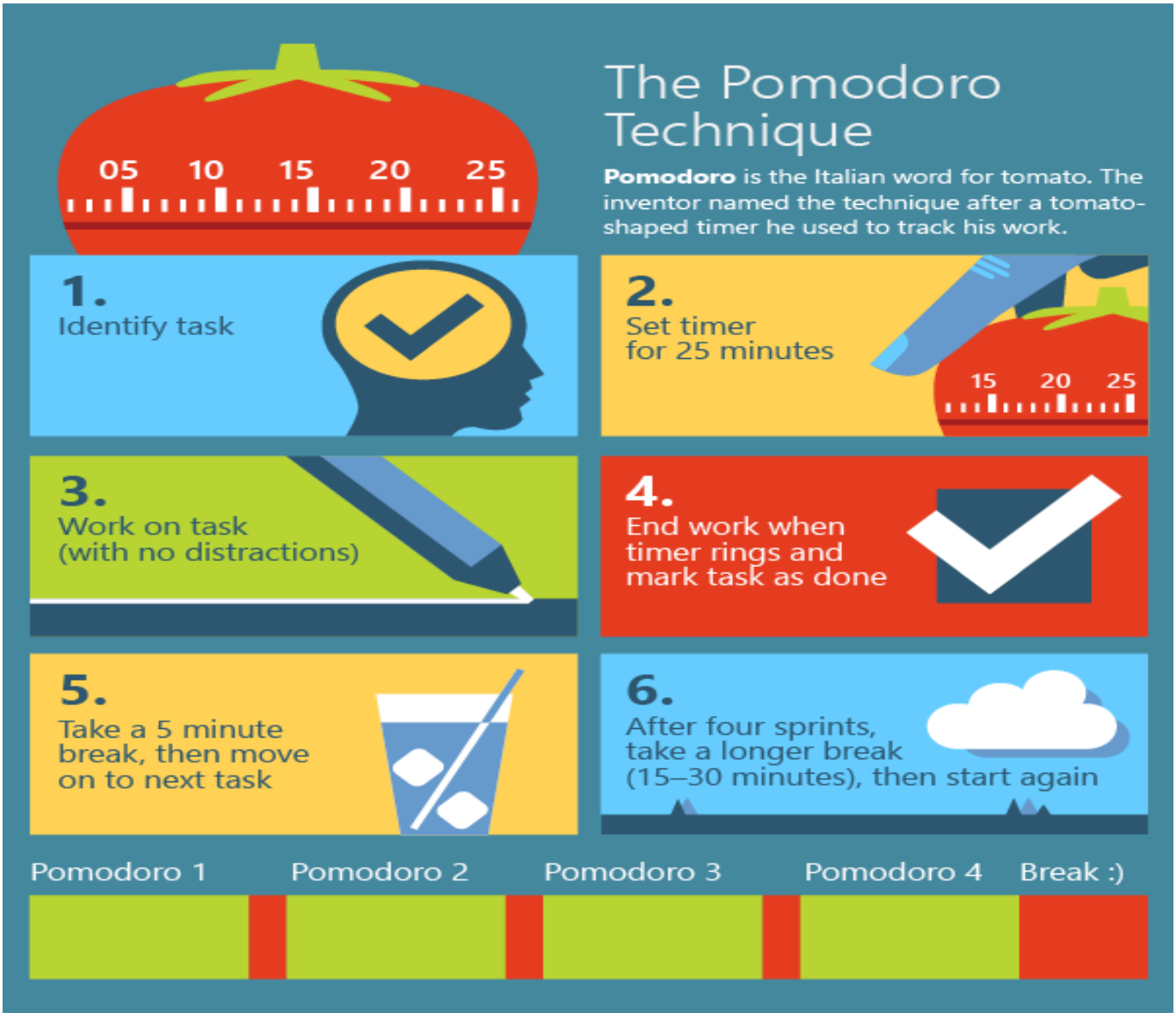
How will you do it?

1. *I'll park the car further away from home and walk a bit longer. I'll also stand up when texting to my friends and checking social media on the mobile phone.*

Remember to set SMART goals! Specific, Measurable, Attainable, Relevant, Timely.

Appendix 2. Pomodoro technique





Appendix 3. Visual cues and apps

You can find a variety of posters related to sitting behaviour, as well as other useful resources, in the following webpage:

https://www.movemoresitless.org.au/download-posters/

Moreover, many **free** apps can help you reducing sitting and introducing physical activity into your daily life.

Mobile device reminder apps (iPhones and iPads)

Move - Daily Activity to Stay Healthy: Get reminded every so often to stand up and do a tiny exercise. Over 300 random workouts keep it exciting (more added every day). Create a healthy habit through occasional reminders. Pick when you do workouts and how often. Choose your reminder sound. Create your own exercises to be absolutely anything you want.

Stand Up! The Work Break Timer: Completely customizable to your work schedule. Set it and forget it. Set your reminder interval to any five-minute increment between five minutes and two hours. The header shows you at a glance how you're doing, and how long to your next alarm. Limit alarms to your office location so it doesn't bug you when you go out to lunch.

Mobile device reminder apps (Android phones and tablets)

Randomly RemindMe: Do you have trouble drinking enough water during the day? Maybe you want a reminder to step away from the computer for a bit. How about a reminder to stop and do push-ups? Trying to make a habit? Or break one? This app will let you set any number of custom reminders that will remind you throughout the day for that and a whole lot more.

Hourly fitness: A simple, time-friendly app, aimed at those who want to be more active throughout the day. Hourly Exercise will remind you to get up and do a basic exercise, once every hour; You may do it, or skip it if you can't do it right then and there.

Computer reminder apps (Windows)

Awareness: This is an app that sets a timer in your menu bar, counting the time you've been active in your computer. Once you reach a specific period of time without taking a break, the sound of a bowl will play, reminding you that it's time to step away for a while. If the app doesn't detect activity in your computer after a set period of time, the timer will reset; however, if you keep working without taking a break, the next time the timer goes off, the sound of the bowl will be played twice, and so forth. The app even includes a link to a website where you can find some useful ideas on how to take advantage of your breaks.

Big Stretch Reminder: Big Stretch is a simple reminder tool that prompts you to take regular breaks and helps prevent the symptoms that come from sitting too long. Alternatively it can be a simple reminder program to tell you when it's your coffee break!

Workrave: This program reminds you to take microbreaks throughout the day and can also help you limit your computer usage while at home. It has settings that let you configure it in a way that works best for you including when to take breaks and how long they should be. This program also gives you examples of exercises that you can do while on a break.

Computer reminder apps (Mac)

Awareness: Awareness helps you become more aware of time spent on the computer by playing the sound of a Tibetan singing bowl to mark every hour of continuous computer use. It also displays how long you've been using your computer without a break in the menu bar. Awareness will never nag you or force you to stop using the computer. Just take a five-minute break whenever you are ready, and Awareness will sense it.

Time Out: Time Out has two kinds of breaks: a "Normal" break and a "Micro" break. You can disable either kind of break if desired, and the breaks are automatically paused when you go away from your computer, and can be reset when you come back. You can configure how long each kind of break lasts, and how long between breaks. Each Time Out is announced via the screen slowly dimming, with related graphics materializing, and when the break is complete, it fades out again.

THINK outside the CHAIR

move more sit less

an Initiative of BLUE EARTH

movemoresitless.org.au

Supplementary file 3: Data collection and intervention text messages

Data collection messages

- Hi! This is just a reminder for you to attach the ActivPAL this morning. Please follow the instructions provided in your activity monitor pack. If you have any doubts or concerns, please contact Oscar on +61 (0) 467 030 290 or oscar.castroserrano@usq.edu.au. Thank you for joining the study!
- Hi! This is just a reminder for you to fill in the ActivPAL Log and the Sedentary Time Questionnaire today. Try to do it as close to your sleeping time as possible, or at 12AM midnight (whichever comes first). Thank you for your participation!
- Hi! It's been 6 days already! Time flies, isn't it? You can remove your ActivPAL device tomorrow, once you wake up. Please remember to return both the device and the daily logs to our research team during the scheduled appointment. In case you have to reschedule the appointment please contact Oscar on +61 (0) 467 030 290 or oscar.castroserrano@usq.edu.au
- Hi! This is just a friendly reminder for tomorrow's appointment with Oscar (ActivPAL study). Campus: XXX Time: XXX Duration: XXX. In case you have to reschedule the appointment or there are some last-minute changes please contact Oscar on +61 (0) 467 030 290 or oscar.castroserrano@usq.edu.au. Thank you for your participation!

Intervention messages

Break up messages (nudges)

- If you've been sitting for more than an hour consider to get up and move! Try walking around or doing some light stretching.
- Warrior, tree, frog, cobra, triangle, cat. Do you know what these words have in common? All of them are yoga poses. You can give them a try! Get creative when it comes to breaking up your sitting time.
- Do you fancy a drink or a snack? Go grab them! This can be a great opportunity to reward yourself and make movement breaks more motivating.
- Have you gone for a walk yet today? It's not too late if you haven't! there are many opportunities to move more throughout the day.

- How about breaking up your sitting now with a 3-minute break? Squats, lunges and jumping jacks are all great ways to kill 3 mins! Try a minute of each and see how many you can do.
- I hope you were able to make many active choices today! Keep it up and soon they will become great healthy habits!
- Thirsty? Make regular trips to the kitchen to refill your water glass and add a few steps into your study sessions.

Health-related messages

- Effects of sitting aren't just long term. As soon as you sit, the electrical activity in the leg muscles shuts off and the enzymes that help break down fat drop. Find ways to move more and sit less.
- Walking burns 5 times the calories that sitting does. Take every opportunity to walk around!
- Whether tending our crops or hunting wild boar, most of our lives as humans were lived on our feet. Our bodies weren't built for sitting and it's starting to take its toll. You might want to stand up for this.
- People with sitting jobs have twice the rate of cardiovascular disease as people with standing jobs. Sit less – move more and more often for a better health.
- University students are a 'high-sitting' group within the general population, so it's important that you pay special attention to your sitting patterns.
- As Bob Marley says, "Get up, Stand up, Stand up for your health". Okay those aren't quite the lyrics, but you get it. Sit less and move more for a better health!
- Humans are built to stand upright. Sitting for long periods can lead to pain and stiffness in your back, neck and shoulders.

Psychological wellbeing and productivity messages

- Interrupting prolonged sitting is important for mental performance. Many university students report breaking up their sitting to 'refresh' their mind and enhance productivity.
- In a recent study examining the relationship between accelerometer-based sedentary behaviour and academic achievement, it was found that university

students who interrupted their sitting time every 30 mins had higher academic scores. Why not give it a try?

- More reasons to sit less – move more and more often? Frequent active breaks have the potential to enhance sustained attention and other cognitive operations associated with academic performance.
- While attention typically decays after 30 minutes performing a task, short active breaks may temporarily restore attention levels. Use your breaks to perform at an optimal level for longer!
- Breaking up sitting time with short walking breaks has been shown to counteract mental fatigue, in comparison with continuous sitting.
- Introducing more movement into your daily life will trigger a feel-good response. And remember, something is better than nothing and more is better than less.
- Sitting less and moving more is a good opportunity to spend more time outdoors. Being outside can lead to significant psychological benefits, such as reduced stress.

Strategies to reduce and break up sitting

- Much of our sitting is automatic or 'mindless sitting' – we don't actually have to be sitting down! We just do it because it's the default position. Look at your day and see what activities you could do standing or walking, rather than sitting.
- Need a tip to sit less? Try walking to uni or the store if you live close enough, or if you drive, park further away from where you are going. It'll add some steps to your day and give you some nice fresh air!
- Sometimes it might be difficult to remember taking breaks. University activities are very absorbing! Your computer or phone can be valuable allies to remind you about standing and moving.
- You would like to move more and sit less but don't know how to start? Set a specific, easily achievable goal for today and try to scale it up progressively. Thinking small is the secret to big success.

- Try to engage other people in your ‘move more sit less’ endeavours. This will make them more pleasant. Also, remember that your own behaviour may be an example for other students to reduce and break up their sitting time.
- You can use habit formation strategies to change your sitting patters. For example, try to consistently pair standing breaks with daily habits such as texting on the phone or drinking coffee.
- Many sitting activities can be converted into active ones. For example, rather than sitting down to read, listen to recorded books while you walk or clean the house. Podcasts are increasingly popular and cover heaps of interesting topics.

Supplementary file 4: Daily log

ActivPAL serial # __ __ __ __ __ __ __

Participant ID: __ __ __ __ __ __ __

Activity Monitor Instructions & Daily Log

Please keep this booklet in a safe place so you can return it to us

Return Appointment: _____ am / pm on _____/_____/_____

If you have any questions or concerns, please contact Oscar on +61 (0) 467 030 290 or oscar.castroserrano@usq.edu.au

Attaching the monitor

1. Sit down on a chair when attaching the monitor so that your thigh is in a horizontal position. This will also make it easier to find the top of your thigh (the crease between your leg and your upper body).
2. The monitor is to be attached one third of the way down between the top of your thigh and top of your knee. Position the monitor in the midline of your right thigh as shown in the picture.
3. Swab the area where the monitor is to be attached with the provided alcohol pad and let the area dry for a few seconds.
4. Place the monitor in the correct position on the thigh, ensuring that the man on the front of the monitor is standing up (head facing upwards) when you stand up.
5. Peel the backing off an adhesive patch (provided in your activity monitor pack) and place it over the monitor. Press the patch onto your skin, starting from the middle out towards the edges and smooth out the air bubbles and wrinkles as much as possible to ensure that the monitor is firmly secured to your thigh.
6. Please wear the monitor continuously (24 hours/day) for 6 consecutive days, removing it on the morning of day 7. The thigh monitor is water resistant (to 1m) so you can wear it whilst showering and swimming in a pool, but please do not wear it in the ocean in case it falls off. The activity monitor can be worn through airport security.

If you need to change the adhesive patch

During your wear time, you may need to change the adhesive patch which attaches the monitor to your thigh. To do this:

- Remove the monitor from your thigh (note that this may cause some slight discomfort) and peel the adhesive patch off the monitor.
- With an alcohol prep pad provided in your Monitor Pack, thoroughly wipe down the monitor and the area of your leg where the monitor was attached and follow the same procedure as explained.

Other notes: Although it is unlikely, skin irritations due to the adhesive tape may occur. If this happens, attach the monitor to the other (left) leg. If you still continue to experience irritation contact the research team for further instructions. The Thigh Monitor will emit a green flash every 6 seconds. This is an indication that it is working and recording data. If you need more info on how to fit the ActivPAL, try this Youtube tutorial:

Video: *activPAL activity monitor* - https://www.youtube.com/watch?v=CHCCX2GW3DM

What else do I need to do?

It is very important that you fill in the **ActivPAL Log** and the **Sedentary Time Questionnaire** every day for the next 6 days while you are wearing the monitor.

How to fill in the daily ActivPAL log

- The log is divided into 6 days. Please complete each question for all of the 6 days. Please try and be as accurate as possible—record the exact times if you can, or at least to the nearest 10 minutes of your estimated times.

- Please fill in each daily log at the end of the day, as close to your sleeping time as possible, or at 12AM midnight (whichever comes first).

- Record the time that you **woke up** and the time that you actually **got out of bed** (these times may be the same for most people). We ask for these two times because people sometimes spend time in bed before going to sleep or getting up and we are interested in distinguishing between actual sleeping time and time in bed before sleep or once awake, for example going to bed and watching TV or reading for an hour before going to sleep.

- Please also record your **'occupational' time**. That is, the time you spend doing any university-related activity (e.g., lectures, tutorials, meetings, independent study, completing assignments, reading, sending emails, etc), unless this was a very short time (less than 15 minutes). Do not include information about any other occupation you may have (e.g., a part-time job).

- If you **remove the device** for longer than 15 minutes during the day, please note down the time that you removed the device, the time that you re-attached it and the reason why you removed the device. This is particularly important, as we cannot tell from the data whether you are lying down or you have just removed the device (the data looks the same when we look at it).

- Then estimate at what time you will **get into bed** and the time that you actually will **go to sleep** time (these times may be the same for most people). This is important as the monitor cannot tell the difference between asleep and awake times, and we are only interested in your activity while you are awake.

- There is also a space for you to make **comments**. It is useful for us to know if you have had any skin irritations, accidentally worn the monitor upside down or any other information that you think we should know. Once you have completed your 6 days of wear, please return both the device and the daily log to our research team during the scheduled appointment.

How to fill in the daily Sedentary Time Questionnaire?

- Please complete the questionnaire for all of the next 6 days. Please try and be as accurate as possible—record the exact amount of time if you can, or at least the closest amount you can think of.

- Please fill in each daily log at the end of the day, as close to your sleeping time as possible, or at 12AM midnight (whichever comes first).

- You will be asked about when you may have been sitting or lying down in the following domains listed below. For each of these, only count the time this was your main activity. Refer to the following instructions on how to properly account for sitting/lying time each day.

    - **Studying**: time spent doing any university-related activity. Examples: lectures, tutorials, meetings, independent study, completing assignments, reading, sending emails, etc.
    - **Work**: paid position only. Examples: babysitting, sitting at the reception, minding a stall/shop, data entry/administrative paper work, tutoring, etc.
    - **Transport**: travelling from one place to another. Please include sitting and waiting for transport. Do not include any time you were standing up while travelling or waiting.
    - **Television Viewing**: watching TV or DVDs or playing games on the TV, such as PlayStation/Xbox. This includes if you watch TV in bed. Do not include watching TV on your computer, such as YouTube.
    - **Computer, Internet, Electronic Games**: include time spent playing games on your phone/tablet, using the internet or activities that were not for studying or working purposes, like Facebook, Twitter, Skype, YouTube, online-shopping, etc.
    - **Sitting for Leisurely Reading**: include recreational reading, but do not include time spent reading for paid work or for study.
    - **Sitting for Eating**: include eating and drinking, meals and snack breaks. If you went out to eat with friends, consider this sitting for socializing and not sitting for eating.
    - **Sitting for Socializing**: include time with friends and family. Include time on the telephone. Do not overlap with other domains such as eating. If you went out to eat with friends, considering this socializing time and not eating time.
    - **Sitting/Lying for Other Purposes**: any sitting/lying time that has not been accounted for in the previously listed domains. This may include hobbies, listening to music, playing an instrument or sitting for religious purposes.

- Do not complete domains as they happen throughout the day, as this may cause you to miss activities that occur later in the day. Please note that this does not include sleep, either in bed or if you fell asleep while doing another activity, for example watching TV.

DAY 1:	**ActivPAL log** Date: _____/ _____ / _____
Sleep	What time did you wake up today? _____:____ am / pm What time did you get out of bed? _____:____ am / pm What time will you get into bed? _____:____ am / pm What time will you go to sleep today? _____:____ am / pm
University	Did you carry out any university-related activity today (e.g., lectures, tutorials, meetings, independent study, completing assignments, reading, sending emails, etc)? Please record all the times you spent doing these activities: ☐ **No** ☐ **Yes** **Time Started** **Time Finished** ___:___ am / pm ___:___ am / pm ___:___ am / pm ___:___ am / pm ___:___ am / pm ___:___ am / pm ___:___ am / pm ___:___ am / pm ___:___ am / pm ___:___ am / pm ___:___ am / pm ___:___ am / pm ___:___ am / pm ___:___ am / pm
Monitor	Did you remove your thigh monitor today for more than 15 minutes? ☐ **No** ☐ **Yes** *If yes, please note time off/on:* Time off: ____:____ am / pm Time on: ____:____ am / pm Time off: ____:____ am / pm Time on: ____:____ am / pm
Other comments:	

DAY 1:	**Sedentary Time Questionnaire** Date: _____/ _____ /_____
Sitting for study	How long were you sitting or lying down while studying today? ☐☐ hours ☐☐ minutes
Sitting for work	How long were you sitting or lying down at your workplace or working from home today? ☐☐ hours ☐☐ minutes
Sitting for Transport	How long were you sitting or lying down for transport today? ☐☐ hours ☐☐ minutes
Television Viewing	How long were you sitting or lying down to watch TV today? ☐☐ hours ☐☐ minutes
Computer, Internet, Electronic Games	How long were you sitting or lying down while using the computer today? ☐☐ hours ☐☐ minutes
Sitting for leisurely reading	How long were you sitting or lying down while reading during your leisure time today? ☐☐ hours ☐☐ minutes
Sitting for eating	How long were you sitting or lying down while eating and drinking today? ☐☐ hours ☐☐ minutes
Sitting for socializing	How long were you sitting or lying down to socialize with family and friends today? ☐☐ hours ☐☐ minutes
Sitting for other purposes	How long were you sitting or lying down today in other pursuits NOT including the time that you have already logged above? ☐☐ hours ☐☐ minutes

Please take a moment to add up your total sitting time for today. Considering how many hours you were awake, does this amount of sitting make sense? If not, please make changes to reflect your true sitting time.

Thank you for your time

Supplementary file 5: Interview schedule for process evaluation

1. Do you feel you've changed your sitting patterns during the past week? How much have you reduced your daily sitting time (e.g., 30 mins, 1 hour)? And in terms of prolonged sitting (e.g., frequency of breaks)? How have you replaced sitting (e.g., walking, standing)?

(If you were not able to introduce changes in your sitting patterns, why do you think this happened? What would need to change for you to reduce and break up your sitting time?)

2. What strategies have you implemented to reduce and break up your sitting time (i.e., what changes have you made in your daily routines)? (How and what worked and what didn't) What helped you to change your behaviour (facilitators)? What prevented you from reducing and breaking up sitting (barriers)?

3. We are interested in knowing why and how you've changed your sitting patterns. In order to explore potential mechanisms of change, I'm going to give you this document, which reflects different reasons for reducing and breaking up sitting expressed by university students.

Could you please indicate, on a scale of 0-10, how much do you think these sentences apply to your own change process during the past week? With 0 meaning that the specific reason for change doesn't apply to you at all and 10 meaning that it completely reflects your reason for change.

4. The following questions refer to the intervention itself. We would like to know your opinion on the different intervention components, so we can improve the design and make additional changes if necessary. Would you change something about the intervention? What? Why?

Let's go through each component. Could you think about (i) how well (or bad) was it delivered/presented (e.g., clarity), and (ii) how useful (or irrelevant) was it for your own behaviour change process?

- Information provided in the face-to-face session and intervention booklet.
- Booklet activities (feedback, pros/cons exercise, suggested strategies).
- Daily text messages to reduce and break up sitting. Were they ‘invasive’ to some extent?
- Materials provided (poster, apps). Did you use any? What was your experience using them?

5. To wrap up, we would like to know more about potential factors, external to the study, that have influenced your sitting patterns during the last two weeks (e.g., weather, high workload). Where the two weeks ‘comparable’?

6. Are there certain periods of the academic year where your sitting patterns are different? Would you say sitting is ‘seasonal’?

7. For what type of activity was it easiest to change your sitting patterns? For what type of activities was it the hardest? (Occupational vs non-occupational; reduce sitting vs break up sitting)

8. Has taking part in the study had any other effects, apart from sitting time?

9. What do you think it will happen to your sitting patterns in the future?

Supplementary file 6: Mechanisms of action questionnaire (statements)

<u>Reason for change</u>: I've changed my sitting patterns over the past week because…
I've learnt more about this particular behaviour and why time spent sitting matters *It doesn't apply to me* **0 1 2 3 4 5 6 7 8 9 10** *It applies to me*
I have now a more negative attitude towards *too much* sitting and a more positive one towards reducing and breaking up my sitting time *It doesn't apply to me* **0 1 2 3 4 5 6 7 8 9 10** *It applies to me*
I'm now aware of the negative consequences of sitting *It doesn't apply to me* **0 1 2 3 4 5 6 7 8 9 10** *It applies to me*
I've developed a conscious decision to reduce and break up my sitting time *It doesn't apply to me* **0 1 2 3 4 5 6 7 8 9 10** *It applies to me*
I've used reminders to reduce and break up my sitting time (e.g., posters, alarms, apps) *It doesn't apply to me* **0 1 2 3 4 5 6 7 8 9 10** *It applies to me*
I've used self-regulation strategies to reduce and break my sitting time (e.g., set specific goals, tracking my own behaviour) *It doesn't apply to me* **0 1 2 3 4 5 6 7 8 9 10** *It applies to me*
I'm now more motivated to reduce and break up my sitting time *It doesn't apply to me* **0 1 2 3 4 5 6 7 8 9 10** *It applies to me*
I've received feedback on how much time I spent in total and prolonged sitting *It doesn't apply to me* **0 1 2 3 4 5 6 7 8 9 10** *It applies to me*
I've developed new skills to reduce and break up my sitting time *It doesn't apply to me* **0 1 2 3 4 5 6 7 8 9 10** *It applies to me*
I consider now reducing and breaking up sitting as part of my role as university student *It doesn't apply to me* **0 1 2 3 4 5 6 7 8 9 10** *It applies to me*
I've used 'prizes' or incentives to reduce and break up my sitting time (e.g., snacks, during the breaks I've reminded myself of the benefits of interrupting sitting) *It doesn't apply to me* **0 1 2 3 4 5 6 7 8 9 10** *It applies to me*
I've realised that people within the university setting encourage and approve reducing and breaking up sitting time. *It doesn't apply to me* **0 1 2 3 4 5 6 7 8 9 10** *It applies to me*
Other people have helped me to reduce and break up my sitting time *It doesn't apply to me* **0 1 2 3 4 5 6 7 8 9 10** *It applies to me*
I now see myself as someone who 'sits less and moves more' *It doesn't apply to me* **0 1 2 3 4 5 6 7 8 9 10** *It applies to me*