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Diabetes Research and Clinical Practice

journal homepage: www.elsevier.com/locate/diabres

International Diabetes Federation

Review

Too much sitting – A health hazard

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ARTICLE INFO

Article history:
Received 17 May 2012
Accepted 17 May 2012
Published on line 9 June 2012

Keywords:
Sitting time
Breaks in sedentary time
TV viewing time
Sedentary behavior
Mortality

ABSTRACT

In contemporary society, prolonged sitting has been engineered into our lives across many settings, including transportation, the workplace, and the home. There is new evidence that too much sitting (also known as sedentary behavior – which involves very low energy expenditure, such as television viewing and desk-bound work) is adversely associated with health outcomes, including cardio-metabolic risk biomarkers, type 2 diabetes and premature mortality. Importantly, these detrimental associations remain even after accounting for time spent in leisure time physical activity. We describe recent evidence from epidemiological and experimental studies that makes a persuasive case that too much sitting should now be considered an important stand-alone component of the physical activity and health equation, particularly in relation to diabetes and cardiovascular risk. We highlight directions for further research and consider some of the practical implications of focusing on too much sitting as a modifiable health risk.

Contents

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http://dx.doi.org/10.1016/j.diabres.2012.05.020

1. Sedentary behavior and cardio-metabolic health – emergence of a new paradigm

Physical activity has been shown to be consistently associated with reduced risk of type 2 diabetes [1], cardiovascular disease [2] and premature mortality [3]. Public-health recommendations on participation in regular moderate-to-vigorous intensity physical activity (sometimes referred to as 'health enhancing exercise') have been widely promulgated, with the aim of reducing type 2 diabetes risk, cardiovascular disease and some cancers [4]. US Federal Guidelines [5] recommend at least 30 min of moderate intensity physical activity on at least five days of the week. It is emphasized that this is in addition to the light intensity activities of daily living (referred to as 'baseline activity'), which includes activities such as standing, walking slowly and lifting light objects. Of concern, however, is that due to changes in personal transportation, communication, workplace and domestic-entertainment technologies, there are significantly-reduced demands to be active [6]. As a consequence, this background level of physical activity is declining. Much of the reduction in activity can be attributed to exposure to environments that demand or encourage *prolonged sitting*.

Time spent in sedentary behaviors (typically in the contexts of television viewing, computer and game-console use, workplace sitting, and time spent in automobiles) are a new focus for research in the physical activity and health field [7–9]. Sedentary behaviors are defined by both their posture (sitting or reclining) and their low energy expenditure – typically in the energy-expenditure range of 1.0–1.5 METs (multiples of the basal metabolic rate) [10]. In contrast, moderate-to-vigorous physical activities, such as brisk walking or running involve an energy expenditure of at least 3 METs [11]. In this perspective, light-intensity activities are those with an energy expenditure range of 1.6–2.9 METs. They can include some occupational duties, household tasks, caring and social activities, and a range of other behaviors. These light-intensity activities are the predominant determinant of daily energy expenditure [12]. However, environmental, social and technological changes have resulted in a high proportion of such normal daily activity being displaced by time spent sedentary [13].

The use of sophisticated activity monitors (that provide valid and reliable duration, amount, frequency, and time of day data on sedentary and activity time) in population-based studies has provided insights into how most adults spend their day, and more specifically, the large contribution that sedentary time makes to adults' overall waking hours [14]. For example, analysis of accelerometer data from over 6000 participants (aged 20+ years) in the 2003–2006 US National Health Nutrition Examination Survey (NHANES) found that mean accelerometer-derived sedentary time across 10 year age categories ranged between 7.3 and 9.3 h/day, with older adults generally the most sedentary [15]. In proportional terms, it can be estimated that some 51–68% of adults' total waking hours are spent sedentary [15,16]. In contrast, moderate to vigorous physical activities accounted for only 5% of the total time across the sample [17], with the remainder (some 27–44%) being spent in light intensity physical activity (LIPA) or 'baseline' activity.

The enhanced measurement capacity provided by activity monitors has also highlighted the strong relationship that sedentary time has with light intensity physical activity. Because time spent in moderate-to-vigorous physical activity is such a small component of overall waking hours, almost all of the variation in sedentary time across the population is related to the extent to which the sedentary time displaces light intensity physical activity [13]. For example, Fig. 1 shows data from NHANES indicating that sedentary time ranged from 6.3 h in the lowest quartile of sedentary time to 10.2 h in the highest quartile of sedentary time. Nearly all of the

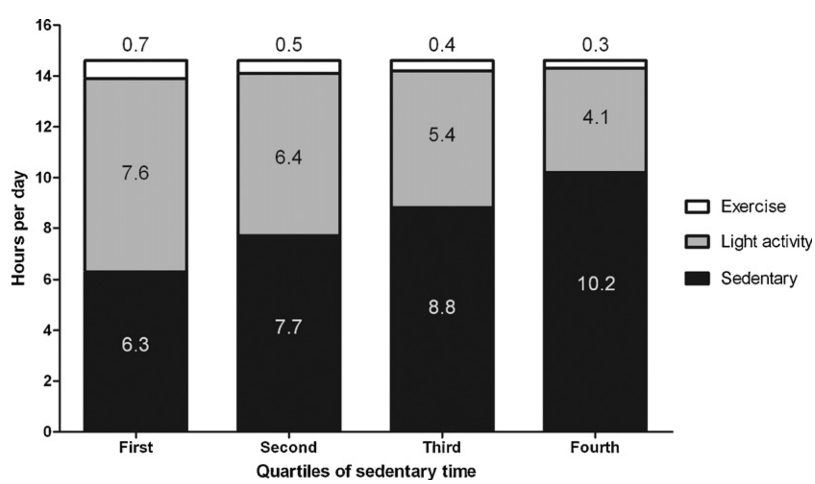

Fig. 1 – Distribution of time (h/day) spent in sedentary, light-intensity physical activity and moderate-intensity physical activity according to quartiles of sedentary time – US National Health and Nutrition Examination Survey (NHANES). Based on 1 week of accelerometer data in 1712 adults from the US National Health and Nutrition Examination Survey (NHANES) [73], the stacked column graphs show the allocation of waking hours spent sedentary, in light activity and in moderate-to-vigorous intensity activity, from the lowest to the upper quartile of overall sedentary time.
Source: Owen et al. [13].

variation in sedentary time can be attributed to less time spent in LIPA. Indeed, one study [18] has reported an almost perfect inverse correlation (−0.98) of the time spent in light intensity physical activity with sedentary time: the more time participants spend in light-intensity activity, the less time they spend sedentary. This suggests that promoting light-intensity physical activity may be a feasible approach to ameliorating the deleterious health consequences of too much sitting. Additionally, epidemiological evidence suggests that having a positive balance between light intensity and sedentary time is desirable because light intensity activity has an inverse linear relationship with a number of cardio-metabolic biomarkers [19].

The distribution of activity time, and the strong relationship between sedentary and light-intensity time, raises novel and significant population health implications, which now require a rethink of the accepted physical activity and health paradigm [20]. As illustrated in Fig. 2, at least half, and up to two-thirds, of adults' waking hours are spent sedentary – which may impart a unique biological stimulus that has deleterious health consequences. Light-intensity activity accounts for the remainder of the time, which – in spite of the overwhelming proportion of waking hours occupied by sedentary behaviors – contributes a large volume of activity relative to the small proportion of time but most adults are involved in MVPA. Yet, the impact of LIPA as a biological stimulus contributing to better health probably has been underestimated significantly.

Within this perspective, the established scientific focus on the health benefits of moderate-to-vigorous intensity physical activity could be likened to hunting – in a rapidly changing environment where prolonged sitting is so ubiquitous and moderate-to-vigorous physical activity so uncommon – for a creature that is small, rare and almost-extinct.

2. The particular health hazards of too much sitting

The notion that prolonged sitting is hazardous to one's health is not new. Ramazzini [21], a distinguished occupational physician, noted as early as the 17th century that a relationship between sedentary behavior and deleterious health consequences were evident in workers whose occupations required them to sit for long hours. In the 1960s, Morris and colleagues [22] reported that workers in occupations requiring primarily sitting (London bus drivers and mail sorters) had a higher incidence of cardiovascular disease than did workers who were required to stand and ambulate (bus conductors and postal delivery workers). In the preceding decade, Homans [23] reported clinical cases of venous thrombosis in the legs following prolonged sitting by theatre-goers and among those spending long hours watching television. Homans recommended that 'such matters are important enough to suggest the advisability of making movements of the toes, feet, and lower legs when one is sitting for long periods and of getting up and exercising when opportunity offers.'

Over the past decade there has been a rapid accumulation of epidemiological evidence – from both cross-sectional and prospective observational studies – to indicate that time spent in sedentary behaviors is a distinct risk factor for several health outcomes. Prominent within this evidence are relationships of sedentary time with both biomarkers of diabetes risk [24–30], particularly obesity [31,32], 2-h plasma glucose [33], lipids and abnormal glucose tolerance [34], and with diabetes as a health outcome [35–38]. Furthermore, these detrimental relationships of sedentary time with health extend beyond markers of diabetes risk. In our recent systematic review of the

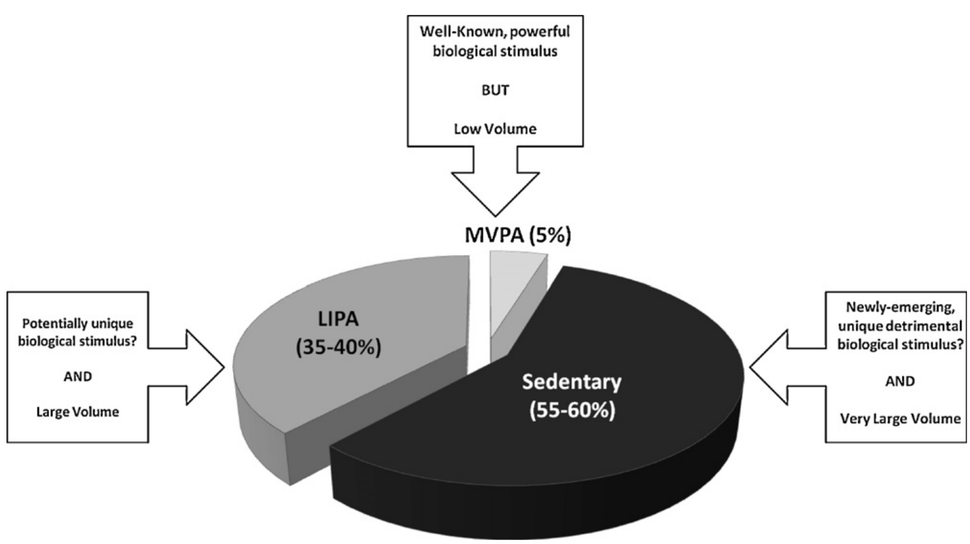

Fig. 2 – Accelerometer measured time spent in sedentary, light-intensity physical activity and moderate-vigorous physical activity in Australian adults (AusDiab) [16]: time to re-think the physical activity and health paradigm? At least half, and up to two-thirds, of adults' waking hours are spent sedentary – which may impart a unique biological stimulus that has deleterious health consequences. Light-intensity activity accounts for the remainder of the time, which – in spite of the overwhelming proportion of waking hours occupied by sedentary behaviors – contributes a large volume of activity relative to the small proportion of time but most adults are involved in MVPA. Yet, the impact of LIPA as a biological stimulus contributing to better health probably has been underestimated significantly.

evidence from longitudinal studies published between 1996 and 2011 [39], we highlighted the growing body of evidence relating time spent in sedentary behaviors with poor health outcomes in adults (see Fig. 3). Importantly, in many of these studies, the associations of sedentary behavior with these adverse outcomes have been shown to persist even when participation in leisure-time moderate-to-vigorous physical activity had been accounted for.

3. Sedentary behavior and premature mortality

Over the past 3 years, nine separate studies have reported on the prospective relationships with premature mortality of self-reported sitting time [40–42]; on TV viewing time and other screen-time behaviors [43–46]; and, on TV viewing time plus other sedentary behaviors [47,48]. Consistently, these studies indicate that time spent in sedentary behavior may be independently associated with increased risk for all-cause and CVD-related mortality in both men and women. Importantly, associations with mortality risk do not appear to be mediated by two important confounders – body mass and time spent in leisure-time moderate-to-vigorous physical activity.

The notion that participation in leisure-time physical activity does not fully mitigate the health risks associated with prolonged sitting is best exemplified in a recent analysis by Matthews et al. [48] of the NIH-AARP Diet and Health study involving the examination of more than 240,000 adults aged 50–71 years. One of the most striking findings of this analysis was that those who reported participating in more than 7 h/week of moderate-to-vigorous physical activity during leisure-time but who also watched television $\geq$7 h/day had a 50% greater risk of death from all causes and twice the risk of death from cardiovascular disease relative to those who undertook the same amount of physical activity but watched television $<$1 h (see figure below). This prompted the authors to question whether leisure-time moderate-to-vigorous physical activity is protective for those who spend large amounts of time in sedentary behaviors; they emphasized the importance of not only engaging in regular physical activity, but also avoiding prolonged periods of sitting.

4. Prolonged unbroken sitting is a contributor to poor health

As already noted, the development of device-based measures of physical activity has provided researchers with sophisticated tools to account accurately for the entire range of activity, from sedentary through to highly vigorous activities in free living participants over a number of days. The most commonly used device-based measure in population-based studies to date has been the accelerometer.

Initial findings from the 2004 to 2005 Australian Diabetes, Obesity and Lifestyle Study (AusDiab) reported that accelerometer-derived sedentary time was deleteriously associated with a number of cardiovascular risk factors, including waist circumference, blood glucose, and triglycerides [16,49]. Intriguingly, adults whose sedentary time was mostly uninterrupted (prolonged unbroken sitting) had a poorer cardio-metabolic health profile compared to those who interrupted, or had more frequent breaks in their sedentary time [49]. These associations were observed even when accounting for total sedentary time and time spent in moderate-to-vigorous-intensity physical activity. When these analyses were replicated using accelerometer data obtained in 4757 participants ($\geq$20 years) from the 2003/04 and 2005/06 population-representative US National Health and Nutrition Examination Survey (NHANES), similar findings were observed. Here, total sedentary time was deleteriously associated with cardio-metabolic biomarkers and the inflammatory biomarker C-reactive protein [18]. Again, there were significant beneficial associations observed with frequent breaks in sedentary time, with breaks in sedentary time favorably associated with waist circumference and C-reactive protein. Importantly, these associations were consistent across age, sex, and race/ethnicity subgroups. The relationship of breaks in sedentary time with waist circumference was also observed in adults with newly diagnosed type 2 diabetes [50]. These epidemiological findings prompted the

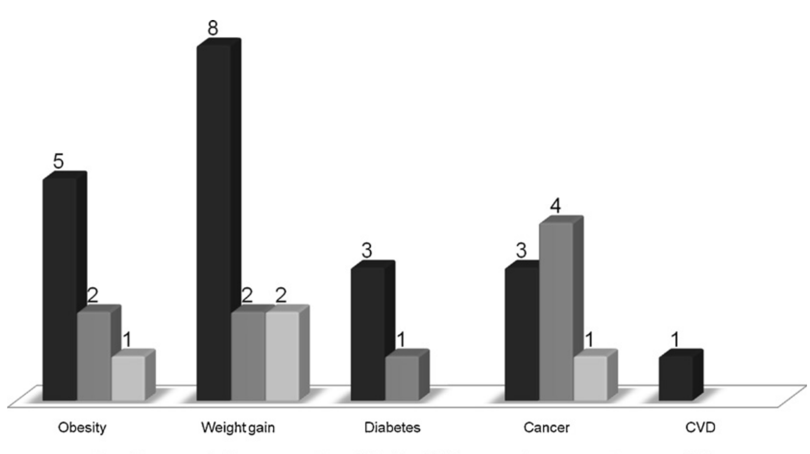

Fig. 3 – Summary of the evidence from prospective studies 1996–January 2011 showing the number of studies reporting the associations of sedentary time with health outcomes [39].
Source: Thorp et al. [39].

inclusion of recommendations specifically addressing frequent breaks from prolonged sitting within the 2011 American College of Sports Medicine's *Guidelines on Exercise for Health Professional* [51].

5. Experimental models addressing the metabolic consequences of prolonged, unbroken sedentary time

The highest priority for the new sedentary behavior and health research agenda is to gather additional evidence from prospective studies, and importantly, new evidence from human experimental work and intervention trials [10]. Understanding the biological mechanisms that underlie associations of prolonged sitting with adverse health outcomes is required in order to identify the specific causal nature of these relationships. To date, few examples exist of human experimental models that specifically address the impact of prolonged sedentary time on cardio-metabolic health parameters.

In a recent review summarizing the data over the last 60 years on the metabolic adaptations to bed rest in healthy subjects, Bergouignan et al. [52] noted that "while bed rest provides a unique model to investigate mechanisms underlying defects induced by physical inactivity in healthy subjects, it is important to remember that bed rest induces a level of physical inactivity likely different (quantitatively and qualitatively) from that observed in the general population". Indeed, it was acknowledged that bed rest may be seen as an experimental model that is too extreme to provide insights relevant to what exists in the general population – where time spent sitting with some level of movement occurs rather than enforced periods of lying down.

On the other end of the activity spectrum, recent studies have reported the deleterious metabolic consequences of transient reductions in physical activity in healthy, active young adults [53,54]. Within this model, active individuals (based on a pedometer step count >10,000 steps per day) were instructed to reduce the number of daily steps (between ~1500 and 5000 steps) with outcomes measured 3–14 days following reduced activity. While such findings have been informative for understanding the rapid alterations that occur in metabolic parameters following reduced activity, the model essentially evaluates the effect of transitioning from an active to a less active state. For modern societies in which for many people the default is excessive sitting and little or no physical activity, it is likely to be more applicable from a population perspective to examine the metabolic effects of sitting and the impact of transitioning from sitting to more active states.

Recent experimental studies have examined the acute impact of prolonged sitting. Among young, non-obese, fit and healthy men and women, significant alterations in whole-body insulin sensitivity were observed after one day of prolonged sitting [55]. The decline in insulin action observed following prolonged sitting (approximately 17 h, measured objectively) was significantly attenuated – but not completely prevented – through the reduction of energy intake by 10,000 kcal/day, so as to approximate low energy expenditure during prolonged sitting. This prompted the authors to conclude that factors other than energy surplus are involved in the detrimental impact of sitting on insulin action. Interestingly, in this study, the detrimental effect on insulin action induced through prolonged sitting was compared to a similar episode (24 h) in which sitting was minimized (~6 h/day) and substituted with more standing (9.8 h/day versus 0.2 h/day) and stepping time (2.2 h/day versus 0.1 h/day). While acknowledging the need for longer term studies, the authors concluded that maintaining at least daily low-intensity activity may assist in minimizing the harmful effects of prolonged sitting on metabolic health.

Building on this evidence and the observational-study findings on breaking up sedentary time described above, we recently examined the acute effects of uninterrupted sitting on postprandial plasma glucose and serum insulin, compared with sitting interrupted by short 2-min bouts of activity (treadmill walking) in overweight middle-aged adults [56]. Using a cross-over design, each participant completed each trial condition over a 7-h period in a randomized order: (1) uninterrupted sitting; (2) sitting interrupted by light-intensity (3.2 km/h) treadmill walking for 2 min every 20 min during the last 5 h; (3) sitting interrupted by moderate-intensity (5.8–6.4 km/h) treadmill walking for 2 min every 20 min during the last 5 h. For all 3 trials, a standardized test drink (200 mL, 75 g carbohydrate, 50 g fat), after an initial 2-h period, with the positive incremental area under curves (iAUC) for glucose and insulin for the 5 h after the test drink calculated for the respective treatments. Fig. 4 illustrates the glucose and insulin iAUC for each individual (ordered by plasma glucose response) across the 3 treatment conditions. Relative to uninterrupted sitting, the glucose iAUC was reduced after both activity-break conditions (light: 24%; moderate 30%). Similarly, the iAUC for insulin was reduced by 23% after the activity-break conditions compared to uninterrupted sitting [56]. Notably, no statistically-significant differences were observed in the glucose and insulin iAUC between the two activity conditions, suggesting that brief interruptions to sitting can lead to significant reductions in postprandial glucose and insulin – irrespective of activity intensity. Whilst the findings are restricted to one-day exposure to prolonged uninterrupted sitting versus interrupted sitting and thus the implications cannot be extrapolated to long-term exposures, the dramatic attenuation in post-prandial glucose and insulin observed in the activity break conditions suggests the importance of briefly breaking up prolonged periods of sitting with activity of at least light-intensity.

The promising findings from these two experimental studies that have specifically addressed the cardio-metabolic consequences of prolonged sitting point to the need for further research. In addition to examining the impact of long-term exposure beyond one day, the various perturbations in the length (short versus long), type (ambulation versus standing) and frequency (high versus low) of activity interruptions to prolonged sitting and possible moderating factors such as sex and adiposity status need to be examined.

Understanding the biological mechanisms underlying the associations observed between prolonged sitting and adverse health outcomes is a research priority. Research from animal studies [57] has suggested that loss of muscle contractile stimulation induced through prolonged sitting has been shown to suppress lipoprotein lipase (LPL) activity, which is necessary for the uptake of the constituents of

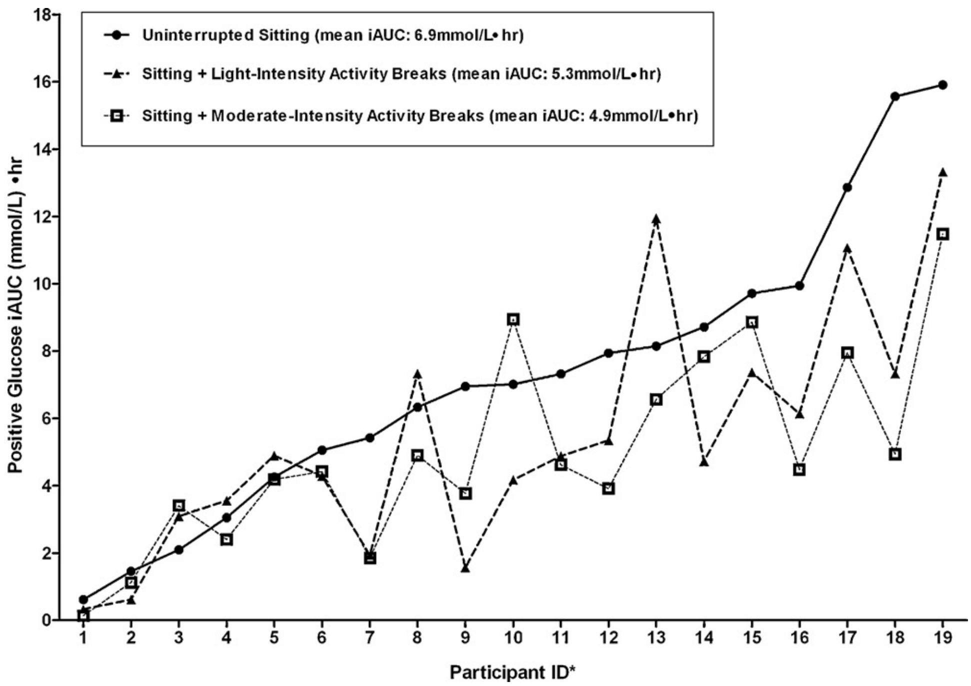

Fig. 4 – The acute effect on the (5-h postprandial) glucose positive incremental area under the curve (iAUC) resulting from uninterrupted sitting, sitting interrupted by light-intensity physical activity breaks and sitting interrupted by moderate-intensity physical activity breaks in the 19 participants of the experimental study [55]. The effect of three trial-conditions: (1) uninterrupted sitting; (2) sitting interrupted by light-intensity (3.2 km/h) activity breaks; and (3) moderate: sitting interrupted by moderate-intensity (5.8–6.4 km/h) activity breaks for each participant on positive (5-h postprandial) glucose iAUC. *Participants ordered according to sedentary glucose iAUC.
Source: Dunstan et al. [56].

triglyceride-rich lipoproteins by skeletal muscle and the production of key substrates for the maturation of HDL particles [58]. Examination of skeletal muscle metabolic regulatory pathways at the epigenetic, gene expression and protein level will likely yield insights into the mechanisms underlying the impact of prolonged sitting on cardio-metabolic risk.

Additionally, it is imperative that the science also moves beyond observational studies to intervention studies conducted in 'real-world' settings targeting the feasibility, acceptability and efficacy of reducing and breaking up occupational, transit and domestic sedentary time. Initiatives such as Project STAND (Sedentary Time ANd Diabetes), a randomized controlled trial which aims to reduce sedentary behavior in younger adults at high risk of type 2 diabetes [59], provide a new direction of behavior change intervention research beyond the conventional approach of encouraging increases in moderate-to-vigorous physical activity in at risk populations. The results of the study, expected in upcoming years, will help to inform future public health initiatives addressing the problem of prolonged sitting the rapidly expanding high risk populations.

6. Public health and clinical implications

On the strength of the evidence that we have reviewed – showing that prolonged sitting time appears to be an important determinant of major health outcomes – we posit that there is now sufficient evidence to assist practitioners and public health experts to expand their thinking beyond just 'purposeful health enhancing exercise'. There are good reasons now to give serious consideration to advocating reductions in sedentary time. Already, some leading health agencies have taken a proactive stance on this issue through the release of new recommendations/advice within physical activity recommendations on the likely importance of reducing sedentary behavior.

- From the United Kingdom, the 2011 *Start Active, Stay Active* document [60] presents guidelines on the volume, duration, frequency and type of physical activity required across the life course to achieve general health benefits. In addition to the well-accepted advice relating to moderate and vigorous physical activity, attention is also directed at reducing sedentary behavior across all age groups, with the non-specific, and sufficiently broad message to "*minimize the amount of time spent being sedentary (sitting) for extended periods*" applied across the various age groups from as the early years to older adults.
- From the USA, the 2011 Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory, Musculoskeletal, and Neuromotor Fitness in Apparently Healthy Adults: Guidance for Prescribing Exercise position stand of the American College of Sports Medicine acknowledges that "*in addition to exercising regularly, there are health benefits in concurrently reducing total time spent in sedentary pursuits and also by interspersing frequent, short bouts of standing and physical*

activity between periods of sedentary activity, even in physically active adults'' [51].

- Both the UK Start Active, Stay Active and the American College of Sports Medicine position stand documents do, however, indicate that in the absence of a coherent body of experimental evidence allowing stronger causal inferences about the health effects of too much sitting, such recommendations relating to sitting will remain general and tentative. Furthermore, the 2010 *Global Recommendations on Physical Activity for Health* document from the World Health Organization [61] is explicit about the potential importance for health outcomes of too much sitting, yet stops short of making specific recommendations around sitting.

Stronger evidence is therefore needed to inform specific recommendations on sitting within future global physical activity guidelines; to develop the relevant clinical and public health guidelines; and, to inform a range of related initiatives [62]. Evidence is required not only on *dose–response relationships* of sitting time with risk biomarkers and health outcomes, but also on the *underlying mechanisms* leading to deleterious health consequences, the feasibility of *changing prolonged sitting* in specific contexts, the *maintenance* of the relevant behavioral changes and the *health benefits* of doing so.

It is likely that the expertise and experience from sectors other than health may be drawn upon in order to develop relevant and effective initiatives aimed at reducing sitting time. For example, the accumulation of additional rigorous scientific evidence on the deleterious health impacts of sitting time in key contexts, such as the workplace, may provide added persuasiveness for occupational health and safety bodies to address the potential implications of prolonged unbroken sitting time in the workplace. Given that workers represent half the global population [63], and most of the population spend an average of one third of the adult life at work [64], the workplace is a fertile setting in which to introduce strategies to reduce sitting time and break up periods of prolonged sitting to improve cardio-metabolic health [65].

In particular, office-based workers are one of the largest occupational groups [66,67] and also highly sedentary [68], making them a key target group for intervention. For many office workers, the bulk of their daily sitting time occurs at work [69,70]. The office is thus a key setting to reduce prolonged sitting time [62,71,72]. This is an important consideration in the context of the duty of care obligations of employers to ensure, so far as is reasonably practicable, the provision and maintenance of a work environment for employees without risks to health and safety. Strategies individuals could consider include:

- standing and taking a break from the computer every 30 min
- taking standing breaks in sitting time during the long meetings
- standing during phone calls
- walking to a colleagues' desk instead of phoning or e-mailing
- using a height-adjustable desk to enable frequent transitions between working in a standing or seated position
- using a headset or the speaker phone during teleconferences to enable more standing during the meeting

The evidence base linking prolonged sitting with a number of adverse health outcomes, including premature mortality, is now sufficiently strong to suggest that physicians should be advising patients to reduce daily sitting time and avoid prolonged unbroken sitting periods. Within the clinical and broader healthcare practice it may be a feasible option to advise patients on reducing their sitting time and increasing their routine light intensity activities as the initial catalyst towards more active living in many patients. Nevertheless, this new perspective on the deleterious health consequences of too much sitting should be seen as being an addition to, and not as an alternative to the well-recognized benefits of participation in health enhancing moderate-to-vigorous intensity physical activity.

7. Conclusions

There is every reason to continue to emphasize the importance of regular moderate-to-vigorous physical activity in the prevention and treatment of chronic disease. However, new evidence linking prolonged sitting time with significant compromises to cardio-metabolic health, indicates that even in physically active adults, concurrent reductions in the amount of time spent sitting is likely to confer health benefits. At present, no definitive recommendations on how long people should sit for or how often people should break up their sitting time exist – more experimental evidence and intervention studies (to provide the relevant dose–response data) are needed to inform specific guidelines and advice that can be given to patients and the general population. At this stage, advice can nevertheless be given with reasonable confidence, to encourage adults to create opportunities to limit their sitting time whilst at home, at work and during transportation and break-up prolonged periods of sitting through frequent transitions from sitting to standing/ambulating throughout the day. A simple strategy message that could be put forward is: '*Stand Up, Sit Less, Move More, More Often*'.

Conflict of interest

There are no conflicts of interest.

Acknowledgements

D.W. Dunstan is supported by an Australian Research Council Future Fellowship. N. Owen is supported by a National Health and Medical Research Council (NHMRC) Senior Principal Research Fellowship. G.N.Healy is supported by an NHMRC (no. 569861)/National Heart Foundation of Australia (PH 08B 3905) Postdoctoral Fellowship.

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