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Too Much Sitting: The Population-Health Science of Sedentary Behavior

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Abstract

Even when adults meet physical activity guidelines, sitting for prolonged periods can compromise metabolic health. TV time and objective-measurement studies show deleterious associations, and breaking up sedentary time is beneficial. Sitting time, TV time, and time sitting in automobiles increase premature mortality risk. Further evidence from prospective studies, intervention trials, and population-based behavioral studies is required.

Keywords

environmental and social change; TV time; breaks in sedentary time; accelerometer measurement; blood glucose; triglycerides; metabolic health

INTRODUCTION

The physical, economic and social environments in which modern humans sit or move within the contexts of their daily lives have been changing rapidly, and particularly so since the middle of the last century. These changes — in transportation, communications, workplace and domestic-entertainment technologies — have been associated with significantly-reduced demands for physical activity. However, these reductions in the environmental demands for being physically active are associated with another class of health-related behaviors.

Sedentary behaviors (typically in the contexts of TV viewing, computer and game-console use, workplace sitting, and time spent in automobiles) have emerged as a new focus for research on physical activity and health (18, 27, 31-33). Put simply, the perspective that we propose is that *too much sitting* is distinct from *too little exercise*. Research findings on sedentary behavior and health have proliferated in the 10 years following publication of our first *Exercise and Sport Sciences Reviews* paper on this topic (32). As we will demonstrate, initial findings on the metabolic correlates of prolonged TV viewing time (TV time) have since been confirmed by recent objective-measurement studies, which also show that breaking up sedentary time can be beneficial. Furthermore, we describe recent studies from Canada, Australia, and the United States, which show prospective relationships of sedentary

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behaviors with premature mortality. Importantly, adults can meet public-health guidelines on physical activity, but if they sit for prolonged periods of time, their metabolic health is compromised. This is a new and challenging area for exercise science, behavioral science, and population-health research. However, many scientific questions remain to be answered before it can be concluded with a high degree of certainty that these adverse health consequences are uniquely due to *too much sitting*, or if what has been observed so far can be accounted for by too little light, moderate, and/or vigorous activity.

The updated recommendation for adults on *Physical Activity and Public Health* from the American College of Sports Medicine and the American Heart Association (ACSM/AHA) “clearly states that the recommended amount of aerobic activity (whether of moderate- or vigorous-intensity) is in addition to routine activities of daily living which are of light intensity, such as self care, casual walking or grocery shopping, or less than 10 min of duration such as walking to the parking lot or taking out the trash” ((20) p. 1426). Logically, doing such daily activities differently could involve reductions in sitting time, but *sitting* per se is not addressed specifically in the recommendations. In this context, the key question to be asked about the strength of the evidence on sedentary behavior and health that we present in this paper is: Would one expect to see a statement on *reducing sitting time* included in future physical activity recommendations?

Sedentary Behavior

Sedentary behaviors (from the Latin *sedere*, “to sit”) include sitting during commuting, in the workplace and the domestic environment, and during leisure time. Sedentary behaviors such TV viewing, computer use, or sitting in an automobile typically are in the energy-expenditure range of 1.0 to 1.5 METs (multiples of the basal metabolic rate)(1). Thus, sedentary behaviors are those that involve sitting and low levels of energy expenditure. In contrast, moderate-to-vigorous physical activity such as bicycling, swimming, walking, or running may be done in a variety of body positions, but require an energy expenditure of 3 to 8 METs (1). In this perspective, light intensity activity behaviors are those done while standing, but that requires expenditure of no more than 2.9 METS.

Addressing research on the health consequences of sedentary behavior requires some initial clarification of terminology. We refer to *sedentary behaviors* (different activities, for different purposes in different contexts; see above). We refer also to *sitting time*, a generic descriptor covering what these sedentary behaviors primarily involve. As we demonstrate below, adults spend the majority of their waking hours either *sitting*, or in *light intensity activity* (predominantly standing with some gentle ambulation).

Time in sedentary behaviors is significant, if only because it displaces time spent in higher intensity physical activity — contributing to a reduction in overall physical activity energy expenditure. For example, displacement of two hours per day of light intensity activity (2.5 METS) by sedentary behaviors (1.5 METS) would be predicted to reduce physical activity energy expenditure by about two MET-hrs/d, or approximately the level of expenditure associated with walking for 30 min per day (0.5 hrs * 3.5 METs = 1.75 MET-hrs).

Research on physical activity and health has concentrated largely on quantifying the amount of time spent in activities involving levels of energy expenditure of 3 METs or more, characterizing those with no participation at this level as “sedentary” (33). However, this definition neglects the substantial contribution that light intensity (1.9 to 2.9 METs) activities make to overall daily energy expenditure (8), and also the potential health benefits of participating in these light-intensity activities, rather than sitting. Furthermore, although individuals can be both sedentary and physically inactive, there is also the potential for high sedentary time and being physically active to co-exist (the *Active Couch Potato*

phenomenon, which we explain below). An example would be an office worker who jogs or bikes to and from work, but who then sits all day at a desk and spends several hours watching TV in the evening.

Common behaviors in which humans now spend so much time — TV viewing, computer use and electronic games, sitting in automobiles — involve prolonged periods of these low levels of metabolic energy expenditure. It is our contention that sedentary behavior is not simply the absence of moderate-to-vigorous physical activity, but rather is a unique set of behaviors, with unique environmental determinants and a range of potentially-unique health consequences (43). Our population-health research perspective is on the distinct role of sedentary behavior, as it may influence obesity and other metabolic precursors of major chronic diseases (type 2 diabetes, cardiovascular disease, and breast and colon cancer).

Sedentary Behavior and Health: A Unique Underlying Biology?

Physiologically, distinct effects are observed between prolonged sedentary time and too little physical activity (17). There are broad consistencies between the patterns of findings from epidemiologic studies on the cardio-metabolic correlates of prolonged sitting that we will describe, and recent evidence on biological mechanisms — “inactivity physiology” — identified in animal models. It seems likely that there is a unique physiology of sedentary time, within which biological processes that are distinct from traditionally-understood exercise physiology are operating. The groundbreaking work of Hamilton and colleagues (3, 16) provides a compelling body of evidence that the chronic, unbroken periods of muscular unloading associated with prolonged sedentary time may have deleterious biological consequences. Physiologically, it has been suggested that the loss of local contractile stimulation induced through sitting leads to both the suppression of skeletal muscle lipoprotein lipase (LPL) activity (which is necessary for triglyceride uptake and HDL-cholesterol production) and reduced glucose uptake (3, 16). A detailed account of findings and implications from Hamilton’s studies has been provided in recent reviews (17, 18).

Hamilton’s findings suggest that standing, which involves isometric contraction of the anti-gravity (postural) muscles and only low levels of energy expenditure, elicits EMG and skeletal muscle LPL changes. However, in the past, this form of standing would be construed as a “sedentary behaviour” because of the limited amount of bodily movement and energy expenditure entailed. This highlights the need for an evolution of the definitions used for sedentary behavior research. Within this perspective, standing would *not* be a sedentary activity and our approach (subject to revision as further findings accumulate) is to equate “sedentary” with “sitting.”

THE METABOLIC HEALTH CONSEQUENCES OF TOO MUCH SITTING

TV Viewing Time: The AusDiab Studies

AusDiab (the Australian Diabetes, Obesity and Lifestyle study) conducted initially in 1999/2000, of a common leisure-time sedentary behavior — TV viewing time — with biomarkers of cardio-metabolic risk. AusDiab recruited a large, population-based sample of some 11,000 adults from all Australian states and the Northern Territory. Some of our first AusDiab findings were that among adults without known diabetes, self-reported TV viewing time was positively associated with undiagnosed abnormal glucose metabolism (12) and the metabolic syndrome (11). The strongest relationships were observed in the highest TV time category (four hours or more per day). When TV time was considered as a continuous measure (10), a detrimental, dose-response association was observed in women between TV viewing time and 2-h plasma glucose and fasting insulin. Importantly, all of these associations persisted after adjustment for sustained moderate-to-vigorous intensity leisure time physical activity and waist circumference. Some of these cross sectional relationships

have been replicated recently in prospective analyses: increases in TV viewing over five-years predicted significant adverse changes in waist circumference for men and women and in diastolic blood pressure and a clustered cardio-metabolic risk score for women. These associations were independent of baseline television viewing time, baseline physical activity and physical activity change, and other potential confounders (48).

Being Sedentary and Meeting Physical Activity Guidelines: The Active Couch Potato

We further examined relationships of TV time with continuous metabolic risk in men and women who reported at least 150 min a week of moderate-to-vigorous intensity physical activity — the generally-accepted public health guidelines for health-enhancing physical activity (20). Among these healthy, physically-active adults, significant detrimental dose-response associations of TV time were observed with waist circumference, systolic blood pressure, and 2-h plasma glucose in both men and women, as well as fasting plasma glucose, triglycerides, and HDL-cholesterol in women only (23). This observation — the *Active Couch Potato* phenomenon — is important. The particular metabolic consequences of time spent watching TV are adverse, even among those considered to be sufficiently physically active to reduce their chronic disease risk. This finding reinforces the potential importance of the deleterious health consequences of prolonged sitting time, which may be independent of the protective effect of regular moderate-intensity physical activity.

TV Viewing Time: Associations with Biomarkers for Men and for Women

One of the striking findings in the AusDiab TV-time studies was that the associations with cardio-metabolic biomarkers were stronger for women than for men (10-12, 23). We subsequently examined the associations of both TV time and self-reported overall sitting time with these biomarkers in the 2004/2005 AusDiab sample (42). The TV time relationships for women were replicated, but for self-reported overall sitting time (which is inclusive of the TV time component), the associations were similar for men and women. So, the question remains as to whether there is a particular relationship of TV time with metabolic health for women. There are some testable hypotheses that can be put forward in this context: Are there dietary or TV time-related snacking differences between men and women? Are women (who have a lower average skeletal muscle mass and a higher average fat mass than men) metabolically more susceptible to the adverse influences of prolonged sitting, following the typically-large evening meal?

Although some of our most striking initial findings on the adverse health consequences of sedentary behavior have been for TV time, there should be caution in treating this common leisure-time sedentary behavior as a marker for overall sedentary time. We have modest evidence (39) that for women, TV time is positively correlated with other leisure time sedentary behaviors and with being less likely to meet physical activity and health guidelines. However, these findings need to be replicated in other populations and with other measures. Furthermore, TV viewing is associated with other health-related behaviors (51) and those in the highest TV time categories are more likely to eat in front of the TV set (26). It is thus plausible that TV time will influence energy balance in two main ways. Most people sit to watch TV and it has a lower energy cost than the alternative activities that it replaces. Also, high levels of TV time are likely to increase energy intake because of prompts from frequent commercials about food and beverages, and unlike for many other activities, the hands are free to eat during TV time (51). It is thus a reasonable hypothesis that this latter factor may partially explain why higher levels of TV time are associated with higher waist circumferences and with adverse blood-glucose and lipid profiles.

We must emphasize that TV time is one of a number of sedentary behaviors that characterise how adults go about their daily lives, and there is potential measurement error associated

with using the self-report measures that are common to most TV-time studies. However, based on our recent systematic review (6), we have some confidence that the TV-time measures that we have used are reasonably reliable and valid.

OBJECTIVE ASSESSMENT OF SEDENTARY TIME: NEW FINDINGS

Advances in the Objective Measurement of Sedentary Behavior

These Australian studies summarised above have all relied on self-reported TV time or overall sitting time. However, advances in measurement technology now provide significantly-enhanced scientific traction, which is helping to deal with the methodological limitation of measurement error related to the use of self-report items. Prior to summarising findings from our objective-measurement studies with AusDiab study participants, it is helpful to consider the new perspectives that emerge when accelerometer data on sedentary time and physical activity are examined. Accelerometers (as distinct from pedometers which count and display number of steps taken) are small electronic devices worn on the hip, which provide an objective record of the volume, intensity, and frequency of activity between and within days, which may be downloaded to computer databases and used to derive scientifically-meaningful activity variables. Accelerometers have been employed as part of the National Health and Nutrition Examination Survey (NHANES), gathering data from large population-based samples of adult residents of the United States. Findings reported to date suggest that, compared to what has been assumed to be the case from self-report surveys, levels of participation in moderate-to-vigorous physical activity are extremely low (44), and that some 60% or more of these adults' waking hours are spent sedentary (29).

Sedentary Behavior during Adults' Waking Hours

To illustrate the overall patterns of activity in adults' daily lives, Figure 1 shows a cluster heat map (49). This is a graphical representation from Genevieve Healy, showing accelerometer data for one individual over one week, in the manner originally presented by Jane Kent-Braun's group (15). The values taken by the accelerometer counts within each minute are represented as colors in the two-dimensional map. The dark blue shading shows accelerometer counts that are below the currently used but still debated cut-off of 100 counts per minute for sedentary time, and which are taken to be indicative predominantly of sitting (a caveat, however, is that some of the minutes shown sedentary will include standing quite still). The pale-blue through to yellow colorings indicate light-intensity through to moderate-intensity physical activities. The yellow through to red indicate moderate-to-vigorous physical activity. From an energy-expenditure perspective, the dark blue translates to very low levels of energy expenditure, with the red reflecting high energy expenditure levels. What is striking in Figure 1 is the extent to which this person spends his or her time either in light-intensity activities (pale blue through to white) and being sedentary (dark blue). While we would not contend that this is a totally precise and unambiguous representation of sitting time, light intensity, and moderate-vigorous activity, it nevertheless is an informative perspective.

Figure 1 illustrates one of our key messages about the role of sedentary time in the physical activity and health equation: it is possible to achieve a level of activity consistent with the public-health guidelines for health-related physical activity (30 min of moderate intensity physical activity on most days of the week) but to spend the vast majority of waking hours involved in sedentary behaviors. In this case, we see that the accumulated moderate-to-vigorous physical activity time is 31 min; however, this person spends 71% of their waking hours in sedentary time. Thus, it is possible for individuals to be physically active, yet

highly sedentary — the *Active Couch Potato* phenomenon identified in the AusDiab TV-time studies (24).

The main scientific caveat for this perspective is that these data show “activity,” which we infer is reflective of “behavior.” However, there are scientific devils in the detail of these objective-movement data: debate remains about what are the most appropriate activity-count cut points to identify sedentary and light intensity time; also, different cut points may be appropriate for adults of different ages, race/ethnicity, and adiposity status.

Objectively-Assessed Sedentary Time: Key Studies

As well as demonstrating remarkably-low levels of physical activity and high levels of sedentary time within contemporary human environments (29, 44), objective measures have also demonstrated the adverse impact of prolonged sedentary time on cardio-metabolic biomarkers of risk. At least three studies in Europe and Australia have examined the associations of objectively-measured sedentary time with continuous cardio-metabolic biomarkers: the ProActive trial conducted in the United Kingdom (UK), the European RISC study, and the AusDiab study (2, 13, 14, 23, 25). For those in the UK ProActive trial (258 participants aged 30-50 yr with a family history of type 2 diabetes), sedentary time was detrimentally associated with insulin in the cross-sectional analysis (14), but was of borderline statistical significance ($p=0.07$) in the one-year prospective analysis (13). Detrimental cross-sectional associations of sedentary time with insulin were also observed in participants of the European RISC study (801 participants aged 30-60 yr, healthy adults), though the associations were attenuated following adjustment for total activity (2). In the AusDiab accelerometer-study sample (169 participants aged 30-87 yr, general population), we observed detrimental associations of sedentary time with waist circumference, triglycerides, and 2-hr plasma glucose (22, 24). It is important to point out that the participants in all of these studies were primarily White adults of European descent (2, 13, 14, 22, 24). A key next step for this research is to examine whether the associations are consistent across different racial/ethnic groups, which is becoming feasible with the public availability of large, multi-ethnic population-based datasets, particularly NHANES (29, 44).

Objectively-Assessed Sedentary Behavior: AusDiab Findings

We used accelerometers to assess sedentary time in a sub-sample of the AusDiab study participants. Sedentary time was defined as accelerometer counts below 100 per minute (see above), and was associated with a larger waist circumference, and more-adverse 2-h plasma glucose and triglyceride profiles as well as a clustered metabolic risk score (22, 24). The associations of sedentary time with these biomarkers (with the exception of triglycerides) remained significant, following adjustment for time spent in moderate-to-vigorous intensity physical activity (22, 24).

As logically would be expected, sedentary time and light-intensity activity time were highly negatively correlated ($r = -0.96$): more time spent in light-intensity activity is associated with less time spent sedentary. This suggests that it may be a feasible approach to promote light intensity activities as a way of ameliorating the deleterious health consequences of sedentary time. Our evidence suggests that having a positive light intensity/sedentary time balance (that is; spending more time in light-intensity than sedentary time) is desirable, since light-intensity activity has an inverse linear relationship with a number of cardio-metabolic biomarkers (22, 24).

Breaks in Sedentary Time: AusDiab Findings

One of the intriguing findings from our accelerometer-measurement studies is that *breaks in sedentary time* (as distinct from the overall volume of time spent being sedentary) were

shown to have beneficial associations with metabolic biomarkers (21). Sedentary time was considered to be interrupted if accelerometer counts rose up to or above 100 counts per minute (21). This can include behaviors that result in a transition from sitting to a standing position or from standing still to beginning to walk. Figure 2 is based on data from two of our AusDiab accelerometer-study participants, showing a simple contrast between adults who have the same total volume of sedentary time, but who break up that time in contrasting patterns. The person whose data is shown in the right-hand panel of Figure 2 (the “Breaker”) interrupts their sedentary time far more frequently than the person whose data are shown on the left panel (the “Prolonger”).

Independent of total sedentary time, moderate-to-vigorous intensity activity time and mean intensity of activity, we found that having a higher number of breaks in sedentary time was beneficially associated with waist circumference, body mass index, triglycerides, and 2-h plasma glucose (21). Figure 3 shows objectively-measured waist circumference across quartiles of breaks in sedentary time. Those in the bottom quarter of the “breaks” distribution had, on average, a 6cm larger waist circumference than did those in the top quarter of that distribution (21).

These findings on breaks in sedentary time provide intriguing preliminary evidence on the likely metabolic-health benefits of regular interruptions to sitting time, which we would argue are additional to the benefits that ought to accrue from reducing overall sedentary time. Interestingly, in a recent study (5), patterns of sedentary time accumulation (but not total sedentary time) were shown to differ among four groups of adults with various activity patterns (healthy group with active occupation; healthy group with sedentary occupation; group with chronic back pain; group with chronic fatigue syndrome). As we will go on to propose, while we believe that these are strongly-indicative findings, there is the need to determine whether these associations can be confirmed in experimental manipulations of sitting time in the laboratory, and in intervention studies where sedentary time is reduced or broken up in naturalistic settings such as the domestic environment or the workplace.

Sedentary Behavior and Mortality

The significance of the evidence on the adverse cardio-metabolic health consequences of prolonged sitting time is underscored by findings from a mortality follow-up of participants in the Canada Fitness Surveys. Canadians who reported spending the majority of their day sitting had significantly poorer long-term mortality outcomes than did those who reported that they spent less time sitting. These relationships with mortality were consistent across all levels of a self-report measure of overall sitting time. Participants estimated the broad fractions of their waking hours that were spent sitting. Importantly, the sitting time-mortality relationships were apparent even among those who were physically active, and were stronger among those who were overweight or obese (25). In a follow-up of AusDiab study participants over 6.5 yr, high levels of TV time were significantly associated with increased all-cause and cardiovascular disease mortality (9). Each one hour increment in TV time was found to be associated with an 11% and an 18% increased risk of all-cause and cardiovascular disease mortality, respectively. Furthermore, relative to those watching less TV (< 2 hours/day), there was a 46% increased risk of all-cause and an 80% increased risk of cardiovascular disease mortality in those watching four or more hours of TV per day, independent of traditional risk factors such as smoking, blood pressure, cholesterol and diet, as well as leisure-time physical activity and waist circumference. A recent study from the United States (47) examined sedentary behaviors in relation to cardiovascular mortality outcomes, based on 21 yr of follow-up of 7744 men. Those who reported spending more than 10 h a week sitting in automobiles (compared to less than four hours a week), and more than 23 h of combined television time and automobile time (compared to less than 11 hours

a week) had an 82% and 64% greater risk of dying from cardiovascular disease, respectively. TV time alone was not a significant predictor (47).

RESEARCH DIRECTIONS

Looking Back through a Sedentary Behavior Lens

Emerging findings on sedentary behavior suggest a different perspective through which findings of earlier physical activity and health research studies may be re-examined (we thank William L. Haskell for stimulating these observations). For example, physical activity epidemiology studies that have assessed physical activity comprehensively have often included measures of sitting time, which has been used mainly to derive overall daily energy expenditure estimates. We would predict (perhaps boldly) that if such studies were to be revisited, with further analyses being conducted using sitting time as a distinct exposure variable, that strong evidence would be found for deleterious effect on subsequent health outcomes, independent of those related to physical inactivity.

Another potentially fruitful area in which the relevance of existing evidence could be re-examined, are the NASA zero-gravity studies. Comparing findings of those studies (that relate to the metabolic consequences of extreme muscular unloading) with those of the recent findings from inactivity physiology (16, 17) may lead yield further insights relating to the underlying biology of prolonged sedentary time.

Research on physical activity and health had its roots in early occupational epidemiological studies that assessed workers in jobs that primarily involve sitting as the comparison groups, against which the protective benefits of physically-active work were highlighted (4, 17, 18). In the perspective of the new evidence that we have highlighted, conducting further occupational epidemiology studies using new objective measurement capabilities, and examining a range of cardio-metabolic and inflammatory biomarkers as intermediate outcomes, could yield valuable insights.

Sedentary Behavior Research Strategy

Our population-health research program on sedentary behavior is guided by the *behavioral epidemiology* framework (34, 36). Figure 4 shows six research phases. As we demonstrate above, evidence within the first phase (examining the relationships of sedentary behavior to cardio-metabolic biomarkers and health outcomes) has strengthened rapidly over the past 10 yr.

Prolonged periods of sitting in people's lives need to be measured precisely (phase ii). Their contextual determinants — that is, *behavior settings* (32, 35) — need to be identified in domestic, workplace, transportation and recreation contexts (phase iii). We have argued previously for a research focus on the distinct environmental determinants of sedentary behaviors, in contexts where they can be amenable to intervention (31, 32, 37, 41). The feasibility and efficacy of such interventions need to be tested rigorously (phase iv). Importantly, public health policy responses need to be informed by evidence from all of these phases. Compared to the challenges for physical activity and public health, sedentary behavior may be less of a "moving target" in this context, and may be shown to be a tractable public health objective (4).

The Population-Health Science of Sedentary Behavior: Research Opportunities

Different sedentary behaviors and their interactions with physical activity need to be examined in a range of contexts. For example, we have demonstrated leisure-time Internet and computer use is related to overweight and obesity in Australian adults (45), and that

habitual active transport reduces the impact of TV time on body mass index (40). Having identified these relationships, our program is now broadening the evidence base through research with other populations. New studies include work with the large population-based dataset from the NHANES from the United States, examining potential racial and ethnic differences in the relationships of total sedentary time and breaks in sedentary time with cardio-metabolic biomarkers. We have demonstrated significant associations of TV time with excess body weight among high school students in regional mainland China (52). In the context of the rapid economic development and increasing urbanisation among the populations of many developing countries, documenting the health consequences of reductions in physical activity and increases sedentary time will be crucial for informing preventive-health measures.

Studies with high-risk groups are also required. For example, we examined accelerometer-derived physical activity, sedentary time and obesity in breast cancer survivors, showing physical activity to be protective, but no deleterious relationship for sedentary time (28). Significant prospective relationships of TV time with weight gain over three years were identified in a large, population-based cohort of Australian colorectal-cancer survivors (48). More such etiologic research is needed, to examine potential relationships between *too much sitting* and the development of other diseases that have been linked to metabolic risk factors.

For the second phase of the behavioral epidemiology framework (measurement; see Fig. 4), there is the need to identify the reliability and validity of self-report instruments (6). Population-based descriptive epidemiology studies using high-quality measures are needed. For example, we have shown that Australian adults with lower levels of educational attainment and living in rural areas are more likely to be in the highest TV time categories (7). We have also demonstrated that, for Australian women, being in the higher categories of TV time can be associated with a broader pattern of leisure-time sedentary behavior and being less likely to meet physical activity recommendations (39). Using American Cancer Society data from a large population-based study, we identified clusters of adults in the four hours or more category of TV time who are less-educated, obese, and snack while watching TV (26).

Studies have begun to identify the environmental correlates of sedentary behavior, and initial findings appear puzzling. Among urban Australians, *lower* levels of objectively-assessed neighborhood walkability (poorly connected streets, low levels of residential density, and limited access to destinations) were found to be associated with *higher* TV time in women (41). However, a recent study in the city of Ghent, Belgium showed *higher* levels of walkability to be associated with *higher* amounts of accelerometer-assessed sedentary time (46). These apparently contradictory outcomes require further research investigation. Such findings have potential implications for the emerging area of research on built environment/obesity relationships, within which sedentary behavior is likely to have a significant role (30).

Research on sedentary behaviors also needs to be extended beyond the promising initial studies of TV time, to understand the potential health consequences of other common sedentary behaviors. Evidence on the metabolic correlates of *prolonged sitting in motor vehicles* would be particularly informative, in the light of recent evidence on relationships with premature mortality (47). The social and environmental attributes associated with high levels of time spent sitting in automobiles also need to be identified.

The highest priority for the sedentary behavior research agenda is to gather new evidence from prospective studies, human experimental work and intervention trials. There is the particular need to build on the promising findings on relationships of sedentary time —

overall sitting time, TV time and time sitting in automobiles — with premature mortality (9, 25, 47). Controlled experimental studies with humans should also be particularly informative. For example, we are currently conducting a laboratory study experimentally manipulating different “sedentary break” conditions, and examining associated changes in cardio-metabolic biomarkers (focusing on triglycerides, glucose and insulin).

Field studies are also needed on the feasibility and acceptability of reducing and breaking up occupational, transit and domestic sedentary time. For example, in a weight-control intervention trial for adults with type 2 diabetes, we are testing the impact of a sedentary behavior reduction intervention module and examining behavioral and biomarker changes associated with reducing and breaking up sedentary time. There are multiple research opportunities that explored through integrating sedentary behavior change intervention into physical activity trials. When accelerometer data are gathered from such studies, sedentary time measures can be derived (21, 22, 24), and unique hypotheses may readily be tested. It is imperative that the field now moves to obtain such evidence through intervention trials, which will take the science beyond the inherent logical limitations of cross-sectional evidence.

Eleven Research Questions for a Science of Sedentary Behavior

1. Can further prospective studies examining incident disease outcomes confirm the initial sedentary behavior/mortality findings?
2. Can sedentary behavior/disease relationships be identified through re-analyses of established prospective epidemiological data sets, by treating sitting time as a distinct exposure variable?
3. What are the most valid and reliable self-report and objective measures of sitting time for epidemiological, genetic, behavioural, and population-health studies?
4. Are the TV-time-biomarker relationships for women pointing to important biological and/or behavioral gender differences?
5. What amounts and intensities of activity might be protective, in the context of prolonged sitting time?
6. What genetic variations might underlie predispositions to sit, and greater susceptibility to the adverse metabolic correlates?
7. What is the feasibility of reducing and/or breaking up prolonged sitting time, for different groups (older, younger) in different settings (workplace, domestic, transit)?
8. If intervention trials show significant changes in sitting time, are there improvements in the relevant biomarkers?
9. What are the environmental determinants of prolonged sitting time in different contexts (neighborhood, workplace, at home)?
10. What can be learned from the sitting time and sedentary time indices in built-environment/physical activity studies?
11. Can evidence on behavioral, adiposity, and other biomarker changes be gathered from “natural experiments” (for example, the introduction of height-adjustable workstations or new community transportation infrastructure)?

PRACTICAL AND POLICY IMPLICATIONS OF A SCIENCE OF SEDENTARY BEHAVIOR

Practical and policy approaches to addressing *too much sitting* as a population-health issue would involve innovations on multiple levels. For example, public information campaigns might emphasize reducing sitting time as well as increasing physical activity. There might be more widespread use of innovative technologies that can provide more opportunities to reduce sitting time (for example, height-adjustable desks) or new regulations in workplaces to reduce or break-up extended periods of job-related sitting. Active transport modes could be promoted not only as opportunities for walking, but also as alternatives to the prolonged periods of time that many people spend sitting in automobiles. Providing non-sitting alternatives at community entertainment venues or events might also be considered. If evidence on the deleterious health impact of too much sitting continues to accumulate as we predict, and if such innovations are implemented, there will be the need for systematic evaluations, particularly of approaches that have the potential for broader dissemination.

Anecdotally, the recent experience in Australia has been that initiatives in the final phase of the behavioral epidemiology framework (“using the relevant evidence to inform public-health guidelines and policy”) have already begun. This is happening largely on the basis of the first-phase evidence presented in Figure 4 (“identifying relationships of sedentary behavior with health outcomes”). For example, the Australian National Preventative Health Task Force Report includes explicit recommendations to address prolonged sitting in the workplace in the context of reducing the burden of overweight and obesity, type 2 diabetes and cardiovascular disease. The Western Australian state division of the Heart Foundation included reducing sitting time in a 2009 state-wide mass media campaigns for obesity prevention. In the state of Queensland, Health Promotion Queensland (a cross-departmental body) commissioned an evidence-based review in 2009 on health impacts and interventions to reduce workplace sitting, with view to future practical initiatives. Thus, there are growing expectations in Australia that too much sitting is a real and substantial risk to health. However, it remains to be seen whether the science of sedentary behavior will deliver consistent new findings in all of the research areas that are needed to inform such innovations (see Fig. 4).

Given the consistency of research findings reported thus far on sedentary behavior and health, we expect that in the near future there will be a stronger body of confirmatory evidence from prospective studies and intervention trials. Furthermore, we predict that the next iteration of the *Physical Activity and Public Health* recommendations of ACSM/AHA will include a statement on the health benefits of reducing and breaking up prolonged sitting time.

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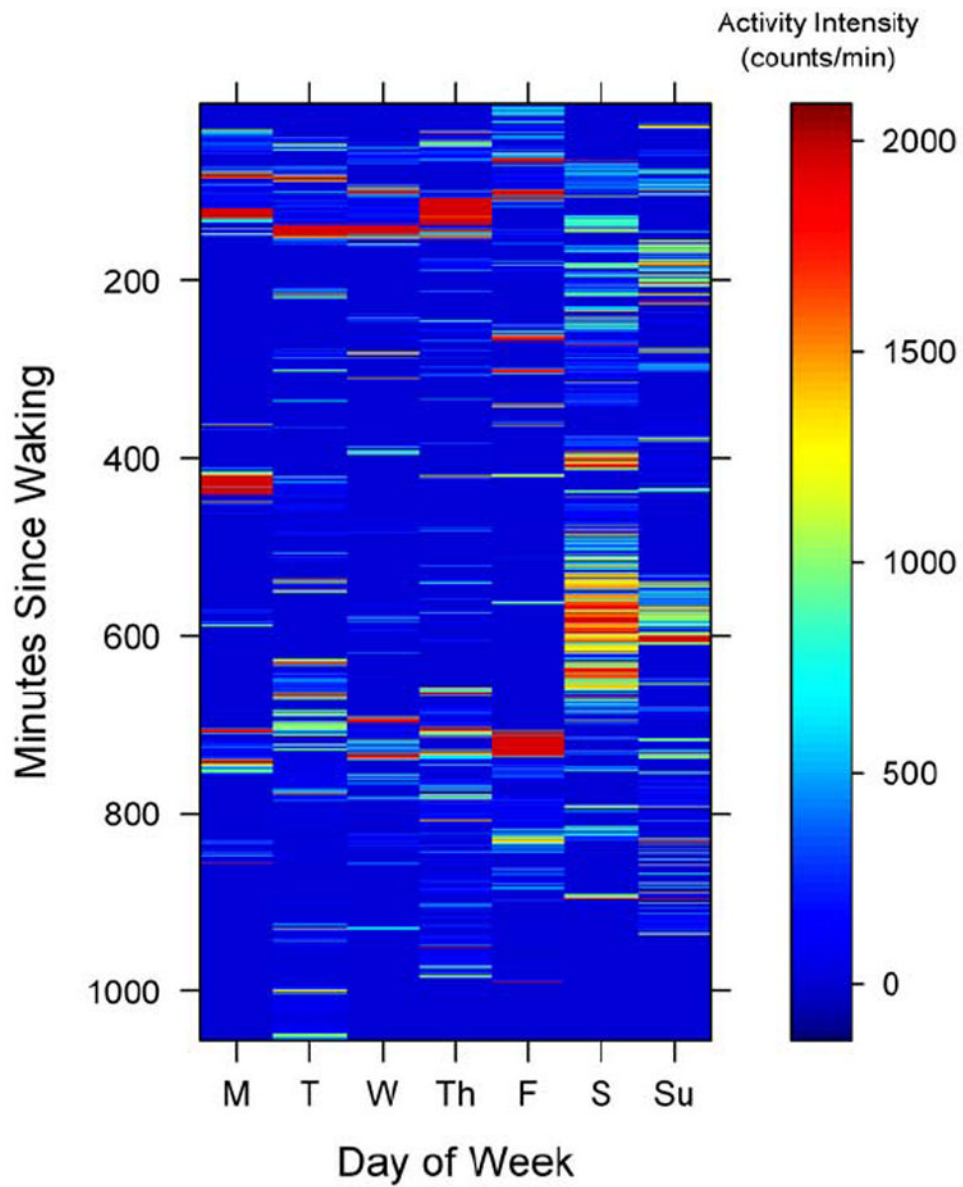


Figure 1. Being physically active, but also highly sedentary: one week of accelerometer-count data showing, on average, 31 mins/day moderate-to-vigorous activity time (> 1951 counts/min) and 71% of waking hours sedentary (< 100 counts/min).

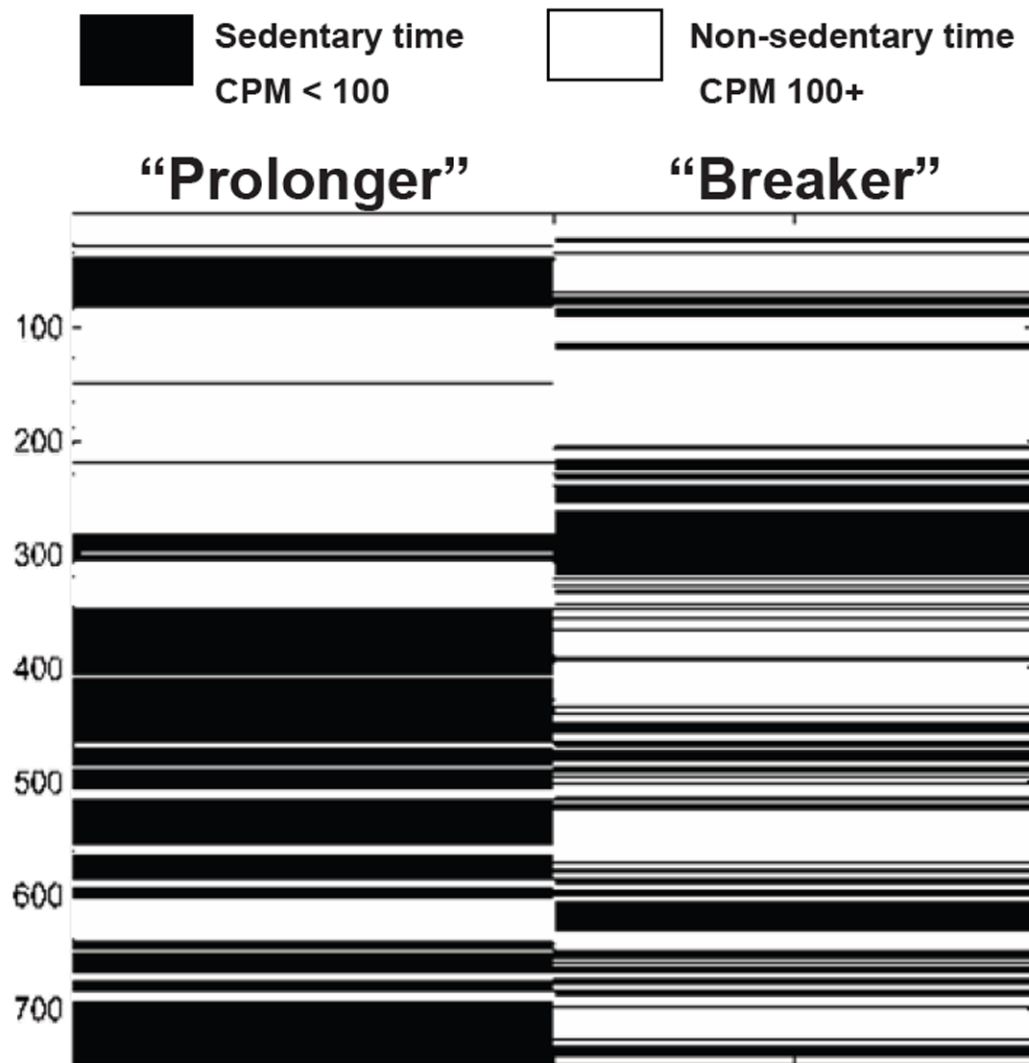


Figure 2.

Breaks in sedentary time: same amount of sedentary time, but different ways of accumulation. CPM = counts per minute. (Reprinted from Dunstan DW, Healy GM, Sugiyama T, Owen N. ‘Too Much Sitting’ and Metabolic Risk – has modern technology caught up with us? *US Endocrinology*. 2009;5(1), 29-33. Copyright © 2009 Touch Briefings. Used with permission.)

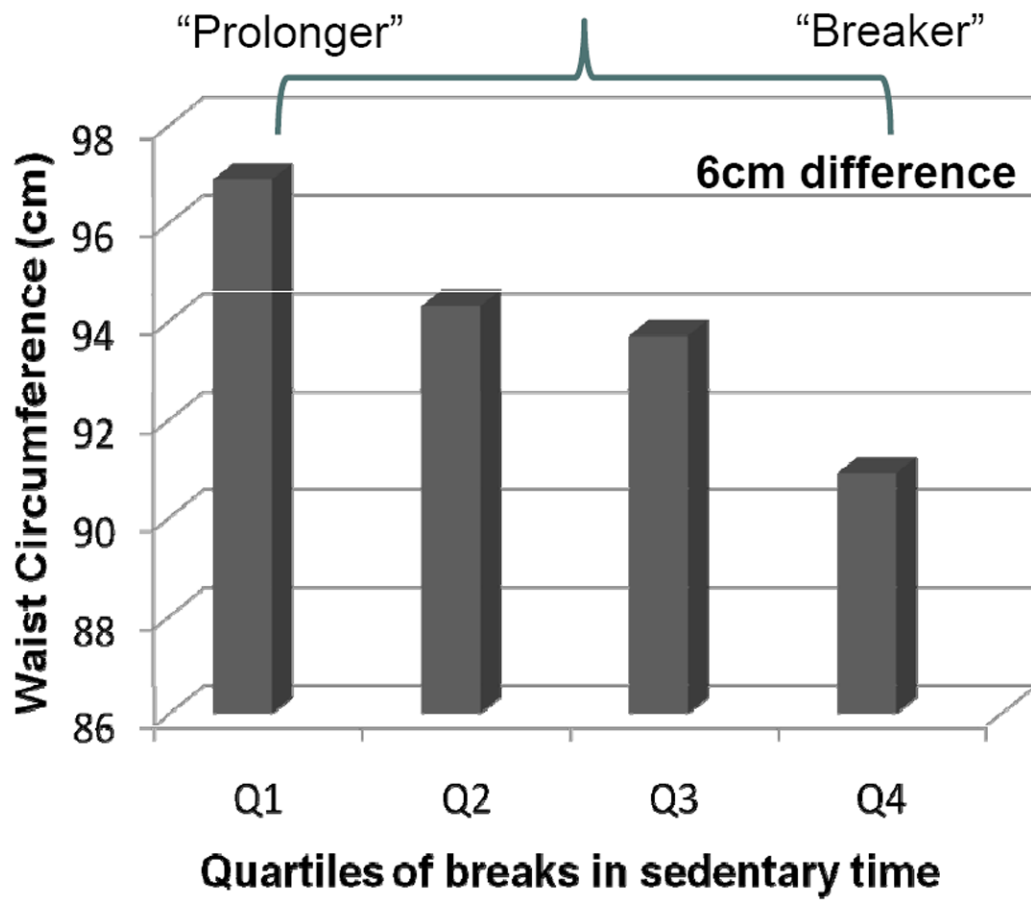


Figure 3. Associations of breaks in sedentary time with waist circumference (based on data from Healy *et al.* (21)).

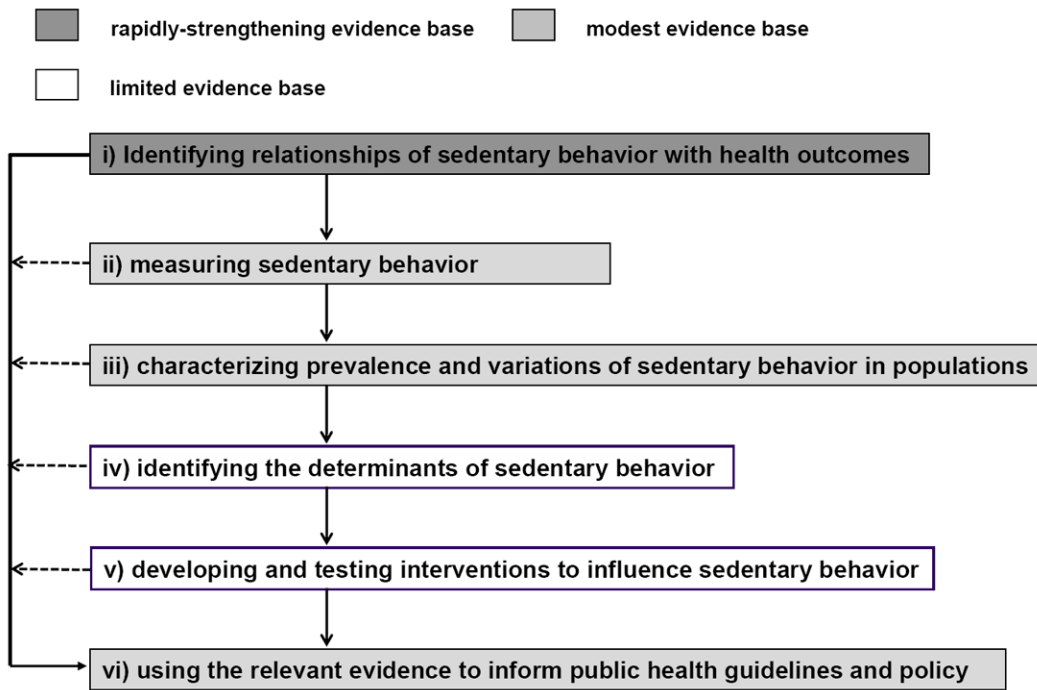


Figure 4. Behavioral epidemiology framework: phases of evidence for a population-health science of sedentary behaviour.