Sedentary Behaviors and Subsequent Health Outcomes in Adults

A Systematic Review of Longitudinal Studies, 1996–2011

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Context: To systematically review and provide an informative synthesis of findings from longitudinal studies published since 1996 reporting on relationships between self-reported sedentary behavior and device-based measures of sedentary time with health-related outcomes in adults.

Evidence acquisition: Studies published between 1996 and January 2011 were identified by examining existing literature reviews and by systematic searches in Web of Science, MEDLINE, PubMed, and PsycINFO. English-written articles were selected according to study design, targeted behavior, and health outcome.

Evidence synthesis: Forty-eight articles met the inclusion criteria; of these, 46 incorporated self-reported measures including total sitting time; TV viewing time only; TV viewing time and other screen-time behaviors; and TV viewing time plus other sedentary behaviors. Findings indicate a consistent relationship of self-reported sedentary behavior with mortality and with weight gain from childhood to the adult years. However, findings were mixed for associations with disease incidence, weight gain during adulthood, and cardiometabolic risk. Of the three studies that used device-based measures of sedentary time, one showed that markers of obesity predicted sedentary time, whereas inconclusive findings have been observed for markers of insulin resistance.

Conclusions: There is a growing body of evidence that sedentary behavior may be a distinct risk factor, independent of physical activity, for multiple adverse health outcomes in adults. Prospective studies using device-based measures are required to provide a clearer understanding of the impact of sedentary time on health outcomes.

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Context

Today's environment is distinctively different from that of the past century. Information and communication technology and labor-saving devices are now ubiquitous across many settings,[1] substantially reducing demands for physical activity and, consequently, energy expenditure.[2] For adults, the most obvious changes evident are in the amount of time that is spent sitting and in sedentary behaviors.

The term *sedentary behavior* (from the Latin word *sedere*, "to sit") describes a distinct class of activities that require low levels of energy expenditure in the range of 1.0–1.5 METs (multiples of the basal metabolic rate)[3] and involve sitting during commuting, in the workplace and the domestic environment, and during leisure.

Findings linking sedentary behavior to adverse health outcomes in adults generally have been confined to observational studies that typically have focused on a specific, yet common, leisure-time sedentary behavior: TV viewing. Two recent reviews[4,5] have summarized the evidence from studies published prior to 2007 that examined the relationships between TV viewing time and health outcomes, including overweight/obesity, cholesterol/lipids, blood pressure/hypertension, blood glucose/type 2 diabetes, and the metabolic syndrome. Although the findings of these reviews indicate consistent relation-

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ships of TV viewing with overweight/obesity and other health outcomes (with the exception of only a few studies), the evidence generally has been generated from cross-sectional analyses. Thus, uncertainty remains as to whether the exposure (in this case, prolonged TV viewing time) occurred before, after, or during the onset of the relevant outcome (adverse cardiometabolic biomarkers; presence of disease).

Building on the cross-sectional evidence, since 2006 there has been a rapid accumulation of findings from longitudinal studies examining the relationships of sedentary behavior with cardiometabolic biomarkers and disease outcomes in adults. Longitudinal studies are essential for strengthening the evidence base on sedentary behavior as an adult health risk. This is because they can provide greater confidence with respect to inferences on the temporal (and thus more likely, causal) nature of the relevant exposure– outcome relationships.

Importantly, many of these recent longitudinal studies have used broader and improved measures of sedentary behavior. There have been improvements on the use of only single sedentary behaviors such as TV viewing, through studies employing global measures of sitting time or combining TV viewing with other sedentary behaviors such as screen-based entertainment and driving time. Further, another important step in the strengthening of the evidence has been the emergence of studies examining the longitudinal relationships between accelerometer-derived (device-measured) sedentary time and health outcomes.

This paper reviews evidence from longitudinal studies published up to January 2011 that have examined relationships of self-reported sedentary behavior and device-measured sedentary time with mortality, chronic disease, and health indicators in adults (aged ≥18 years). This builds on previous reviews that have summarized findings from longitudinal studies up to 2006[4,5] or in relation to domain-specific sedentary behavior (occupational sitting)[6] in adults. Proper et al.[7] recently published a systematic review of 19 studies that summarized prospective associations between self-reported sedentary behaviors and health outcomes in adults up to February 2010. In the review, the authors used a best-evidence synthesis approach based on a standardized set of predefined criteria for informativeness and validity/precision to draw conclusions on the relationship between sedentary behavior and health outcome. As a result of this approach, a number of studies were not included in that review.

Here, the previous review is built on with an examination of evidence from all of the prospective studies that report on a range of health outcomes across diverse adult populations. Specifically, it will summarize the findings from all of the studies without prejudice of the methodologic quality of the studies. Further, it will include prospective studies that report relationships with health outcomes from childhood and/or adolescence through to adulthood. Remaining evidence gaps and future research directions will also be discussed.

Evidence Acquisition

Description of Search and Selection Process

Three search strategies were applied to identify relevant literature for this review. In June 2010, four existing literature reviews on the association of sedentary behavior and health outcomes initially were screened for any publications that matched the current inclusion criteria.[4,5,8,9] A systematic literature search was then conducted in Web of Science, MEDLINE, PubMed, and PsycINFO using three blocks of terms to identify additional papers not reported in the reviews. The first search targeted the longitudinal design (cohort, longitudinal, prospective, prospectively); the second search targeted the behavior (screen time, sedentary, sitting, television, TV); and the last search specified the health outcomes of interest (adiposity, BMI, body mass index, cancer, cardio metabolic, cardiovascular, CVD, diabetes, health, hypertension, insulin resistance, insulin sensitivity, metabolic disease, metabolic risk, metabolic syndrome, mortality, obese, obesity, overweight, weight gain, weight maintenance, weight loss maintenance). All searches were limited to English-language peer-reviewed journal articles. The final search strategy was conducted from June 2010 to January 2011 and involved screening reference lists of publications that matched the current inclusion criteria and other publications (in press at the time) of which the authors were aware to identify eligible papers.

Study Inclusion and Exclusion Criteria

Twelve papers were identified through screening reference lists of previous reviews on a similar topic.[5,8,9] The subsequent search across the four databases resulted in 1276 publications matching the terms. After the exclusion of duplicate articles (n=771) and studies targeting a non-adult sample (n=226), 279 papers were left for potential inclusion. Of these, 227 papers were further excluded on the grounds that the topic investigated was irrelevant for this review, and another 27 were excluded because they utilized a cross-sectional design. Hence, 25 journal articles identified through these databases were left for inclusion. Another 11 papers (n=6 in press at the time) were identified through the authors. Thus, 48 journal articles eventually were included for this review.

Data Extraction

All publications included were examined independently by two of the authors. Data extracted from each article included information on the sample characteristics, the length of follow-up, the health outcome being assessed, the type of sedentary behavior, and its measurement. Meta-analyses of the 48 studies identified were not conducted because of the sizeable heterogeneity in the specific measures of sedentary behavior reported.

Evidence Synthesis

Of the 48 studies identified, 43 used a self-reported measure of either total sitting time ($n=9$); TV viewing time only ($n=12$); TV viewing time and other screen-time behaviors ($n=14$); or TV viewing time plus other sedentary behaviors ($n=8$). Two studies used both a self-reported measure of total sitting time and TV viewing time and other screen-time behaviors; two used a device (heart rate or accelerometry) measure of sedentary time; and one used both a device measure of sedentary time and a self-reported measure of TV viewing time and other screen-time behaviors.

In Appendix: A (available online at www.ajpmonline.org), findings are presented from the 48 studies according to the measure of sedentary behavior reported (self-reported sitting time, device measure of sedentary time) and by relationship with specific categories of health outcomes (mortality, disease incidence, overweight or obesity/weight gain, and other health outcomes). Studies that report relationships with more than one health outcome are described in multiple categories in the table ($n=2$). Additionally, studies that report relationships with multiple measures of sedentary behavior for a specific category of health outcome are described separately for each measure in the table ($n=3$).

Three studies investigated the relationship of self-reported sitting time with mortality,[10–12] one examined the relationship with cardiovascular disease,[13] four examined the relationship with cancer risk including all cancers,[14] endometrial,[15] colon,[16] and ovarian cancer[12] and three examined the relationship with weight gain.[17–19] Twelve studies examined the relationship among self-reported TV viewing time (hours/day); incident diabetes[20]; incident symptomatic gallstone disease[21]; obesity (measured by BMI)[22–27]; gain[28–30]; cardiometabolic risk[27]; and abnormal glucose tolerance.[31]

Seventeen studies examined the relationship between health outcomes and TV viewing and other screen-based entertainment ("screen time"), which included watching videos and/or using a computer, playing video games. Three studies specifically examined the relationship with mortality risk,[32–34] with one of the studies additionally examining risk for CVD events[32]; two studies examined the relationship with incident[35] and gestational[36] diabetes; five studies examined the relationship with disease incidence including cholecystectomy,[37] chronic kidney disease,[38] mental disorders,[39] and endometrial[15] and colon[16] cancer; two studies examined the relationship with cardiometabolic risk biomarkers[34,40]; and one study with risk of insulin resistance.[41] The remaining five studies examined the relationship with overweight or obesity[42,43] and weight gain.[44–46]

Eight studies examined the prospective relationships between self-reported TV viewing time plus other sedentary behaviors (including time spent on such activities as watching TV and videos, and riding in a car) and CVD-related mortality[47]; incident diabetes and obesity[48]; incident endometrial cancer[49,50]; incident cholecystectomy[37]; incident hypertension[51]; and weight gain.[52,53]

Three studies have investigated relationships of device-measured sedentary time with insulin resistance[41,54] and weight gain.[55] Two of the studies used HR monitoring to determine time spent sedentary (% of daytime hours),[54,55] whereas the other used accelerometry (minutes/day).[41]

Summary of Results

A summary of the impact of sedentary behavior by each category of health outcome is provided in the following section.

Mortality

With the exception of one study that reported associations for men only,[10] time spent in sedentary behavior has been shown to be consistently associated with increased risk for all-cause, CVD-related, and all-other-causes mortality in both men and in women[11,32–34,47,56] independent of BMI and physical activity. Of the four studies that additionally examined cancer-related mortality risk,[11,33,34,56] only one reported a significant association with self-reported sitting time (in women only), which was independent of BMI and physical activity.[56] Based on these findings, there is a convincing level of evidence that a longitudinal relationship exists between sedentary behavior and all-cause, CVD-related, and all-other-causes mortality risk in men and in women.

Disease Incidence

In general, consistent findings exist with respect to engaging in high levels of sedentary behavior and increased risk for diabetes[20,35,36,48] and site-specific cancers; including ovarian,[12] colon,[16] and endometrial[15,49,50] cancer. However, the extent of the mediating effect of both BMI and time spent in physical activity in these associations has not fully been elucidated. Relative risk for disease incidence was significantly attenuated in four[15,20,36,50] of the eight studies once adjustment was made for these potential confounders. Associations for endometrial cancer and diabetes (including gestational diabetes) risk were most attenuated. At present, there is limited evidence to conclude that a longitudinal relationship exists between sedentary behavior and risk of diabetes and cancer incidence.

Sedentary behavior was significantly associated with increased incidence of cardiovascular disease,[13] symptomatic gallstone disease,[21] and mental disorders,[39]

largely independent of physical activity time. However, caution is warranted in the interpretation of these findings as the conclusions drawn are based on a limited number of studies. Further studies are required to confirm a longitudinal relationship.

Overweight or Obesity Incidence/Weight Gain

Greater time spent in sedentary behavior was consistently associated with increased risk for obesity.[23,24,42,48,57] However, in older adults, baseline BMI appeared to mediate the association.[23,43] With the exception of three studies that showed either no relationship,[29] a relationship in men only,[46] or a relationship in women of normal weight at baseline only,[52] elevated levels of sedentary behavior were consistently associated with weight gain[18,19,44–46,53] in both men and in women. Importantly, these associations remained following further adjustment for physical activity.[18,19,44–46]

Mixed findings have been observed with respect to measures of obesity. Six of the ten studies found in both men and in women that sedentary behavior significantly predicted adverse changes in BMI[22,24–27] and waist circumference,[58] largely independent of baseline BMI or physical activity. The remaining four studies either showed gender-specific associations,[28,30] no association[29] or that time spent sedentary was a determinant of changes in body weight.[55]

During childhood and/or adolescence, engagement in sedentary behavior was consistently shown to predict obesity[24,26] and increased BMI[22,24,26,27] in adulthood. These relationships were independent of BMI during childhood/adolescence and time spent in physical activity.

Based on the findings, there is limited evidence that a longitudinal relationship exists between sedentary behavior, weight gain, and risk of obesity in adults. However, there is a reasonable level of evidence to conclude that sedentary behavior during childhood and adolescence is a strong predictor of obesity and detrimental changes in indicators of obesity during adulthood.

Other Health Outcomes

Increased sedentary behavior was shown to be adversely associated with a clustering of cardiometabolic biomarkers[58] in women but not men. Individual cardiometabolic biomarkers including leptin[40] and cholesterol[27] were also positively associated with sedentary behavior. It is unclear from the limited evidence to date whether sedentary behavior is prospectively associated with insulin resistance,[41,54] abnormal glucose tolerance (in pregnant women only),[31] and hypertension.[51]

There is insufficient evidence to conclude that a longitudinal relationship exists between sedentary behavior, markers of cardiometabolic health, and metabolic conditions.

Mediating Effect of Physical Activity in Associations of Sedentary Behavior and Health Outcomes

Thirty-four of the 48 studies included in the review adjusted for some measure of physical activity (e.g., total physical activity, physical activity energy expenditure, physical activity status, domain-specific physical activity time) in their prospective analyses. Importantly, only two of these studies did not report significant associations for sedentary behavior and health outcomes[14,17] after adjustment. Seven[26,28,35,36,43,44,55] of the 34 studies adjusted for physical activity subsequent to their multivariate model. With the exception of one study,[26] further adjustment for physical activity did not attenuate significantly the reported associations. In the study by Viner and Cole,[26] additional adjustment for physical activity attenuated the significant association between watching TV on weekdays at age 5 years and BMI *z*-score at 30 years. However, the association for weekend days remained.

Seventeen studies[11,12,25,32–36,39,40,42,43,45,47,48,51,56] examined the joint effect of physical activity and sedentary behavior on health outcomes. Five studies[11,25,33,34,43] used interaction terms in multivariate models to assess the relationship between physical activity and sedentary behavior on health outcomes, whereas the others stratified according to categories of physical activity. Interaction tests revealed that leisure-time[11,33] and total weekly physical activity[25,34,43] did not modify significantly the reported associations of sedentary behavior (sitting and TV viewing time) with mortality risk,[11,33,34] risk of being overweight,[43] and changes in BMI.[25] Stratifying by categories of physical activity was not shown to attenuate associations of categories of sedentary behavior with risk of mortality,[11,34,56] overweight/obesity,[42,43,48] BMI/weight gain,[25,45] diabetes,[35,36,48] hypertension,[51] and ovarian cancer.[12]

In three studies,[32,39,47] physical activity provided protection from the deleterious associations observed between sedentary behavior and the incidence of mental disorders,[39] CVD events,[32] and CVD mortality.[47] For instance, when stratifying by physical activity status (active or inactive), CVD mortality risk was shown to be significantly associated with only time spent riding in a car or a composite sedentary behavior measure in physically inactive men/boys but not in physically active men/boys. In the study, the authors concluded that physical activity may have a protective role in the relationship between sedentary behavior and CVD mortality risk.[47]

Based on the findings, there is a reasonable level of evidence to conclude associations between sedentary be-

havior and health outcomes are not mediated by time spent in physical activity.

Discussion

This paper builds on previous reviews of sedentary behavior, specifically focusing on prospective studies conducted in adults from 1996 to January 2011. There is now an emerging body of evidence to indicate that sedentary behavior may be a distinct risk factor for multiple health outcomes, including mortality. Further, the adverse relationships observed with sedentary behavior in many of these longitudinal studies have been shown to persist even when physical activity has been accounted for within the analysis.

For all of the health outcomes assessed in this review, the relationship between sedentary behavior and premature mortality, specifically all-cause and CVD-related mortality, was the most consistent across studies in both men and women.[11,32–34,47,56] However, caution is warranted with respect to drawing inferences on the causal role of sedentary behavior in mortality risk, because only six studies to date have examined this relationship. Additional studies will help validate this relationship.

Generally, a consistent pattern of findings has been reported in relation to disease incidence, with time spent in sedentary behavior being linked to increased risk for site-specific (ovarian, endometrial and colon [in men only]) cancer[12,15,16,50] and diabetes.[20,35,36,48] Multivariate analysis did, however, indicate that these detrimental associations may be a consequence of overweight/obesity because further adjustment for BMI attenuated several of the reported relationships, particularly in relation to cancer incidence. This is not surprising given the clear links between obesity and cancer risk.[59]

Increased risk of cardiovascular disease,[13] symptomatic gallstone disease,[21] mental disorders,[39] and hypertension[51] were shown to be associated with time spent in sedentary behavior independent of physical activity time. However, the limited number of studies precludes any definitive conclusions from being drawn. Consistent with another review on this topic,[7] our review indicates that there is no clear evidence of a relationship between sedentary behavior and prospective changes in cardiometabolic risk and metabolic markers. Inconsistencies among studies that examined associations with cardiometabolic markers was somewhat unexpected giving that a consistent relationship had been observed for time spent in sedentary behavior and CVD-related mortality risk.

Results from the 24 studies investigating prospective relationships of sedentary behavior with obesity incidence,[23,24,26,42,43,48] weight gain,[17,19,45,46,52,53] weight maintenance,[18,44] and measures of obesity (including BMI and waist circumference)[22,24–30,55,58] have been somewhat mixed. Although there is a growing body of evidence to suggest engaging in sedentary behaviors during childhood or adolescence is a strong predictor of obesity/weight gain in adulthood[22,24,26,27] particularly for women/girls, the findings from studies in adults relating to obesity/weight gain were less convincing than reviews[5] previously have indicated. Although the majority of studies measuring self-reported sedentary behavior have reported significant associations with weight gain/obesity in adults, in several studies, these associations were no longer evident following adjustment for baseline BMI[23] and BMI at follow-up.[43]

One study also found a significant association only in those adults who were of normal weight status at baseline.[52] This raises the possibility that sedentary behavior and weight gain in adults may be mutually reinforcing. It also suggests that initial weight status may be an important determinant of how much weight is gained by adults who have a high level of engagement in sedentary behavior. Recent evidence from a study utilizing a device measure of sedentary time supports this notion, because markers of obesity at baseline predicted adults' sedentary time at follow-up but not vice versa.[55] Some of the inconsistencies in weight gain might also be explained by the duration of follow-up used in the studies, with most of those that reported significant associations following adjustment for BMI having a longer follow-up period than those that were significantly attenuated.

It is important to acknowledge that although several studies reported significant associations between sedentary behaviors and weight gain in adults, the effect size (usually described in terms of a change in BMI) generally has been small. Three studies categorized weight gain as either $\geq$5 kg,[44] $>$5 kg[19] and $\geq$4.5 kg[52] and reported significant associations. However, only two[18,53] examined the relationship between sedentary behavior and clinically significant weight gain (defined as gaining $>$5% of baseline weight).[60] Further studies that specifically investigate the effect of sedentary behaviors on clinically significant weight gain are required to strengthen the evidence with respect to weight gain in adults.

The evidence supports earlier reviews by Williams et al.[5] and Foster et al.[4] that there is generally a consistent relationship between time spent watching TV and weight gain/obesity risk in adults. However, for total sitting time and other sedentary behaviors ("screen time" and TV viewing time and other sedentary behaviors) findings are mixed. Several studies have reported gender-,[28] income-,[28] BMI-,[52] and age-specific[46] relationships with overweight/obesity risk in adults.

The exact mechanisms by which engaging in sedentary behavior increases mortality risk and other poor health outcomes in adults is yet to be elucidated. There are several postulated mechanisms that may be complex in nature and potentially also bidirectional in their influence. From a physiologic perspective, animal studies by Hamilton and colleagues[61–63] have demonstrated that a loss of local contractile stimulation (which typically occurs during sitting or lying down) leads to the suppression of skeletal muscle lipoprotein lipase (LPL) activity. LPL is the rate-limiting enzyme involved in the uptake of triglycerides and free fatty acids into skeletal muscle and high-density lipoprotein (HDL) cholesterol production. Importantly, the suppression of LPL activity is not observed when experimental animals engage in incidental, light-intensity activity such as standing or walking. Loss of local muscle contraction may also reduce glucose uptake through blunted translocation of GLUT-4 glucose transporters to the skeletal muscle cell surface.[61,64.]

Elevated levels of glucose, triglycerides, and free fatty acids in the circulation can generate excess free radicals and trigger a biochemical cascade of inflammation, endothelial dysfunction, hypercoagulability, and increased sympathetic activity. Sustained over a significant period of time, such events potentially can create a milieu that is conducive to the development of coronary heart disease and cardiovascular risk factors.[65]

As suggested in the review by Williams et al.,[5] engaging in sedentary behaviors potentially may also promote weight gain by reducing adults' opportunities for engagement in light-intensity, incidental activities, and by increasing energy consumption. Healy et al.[66] recently showed using accelerometers that light-intensity activity is highly inversely correlated to sedentary time in Australian adults, with more modest correlations shown with moderate-to-vigorous activity. Displacement of spontaneous movements and intermittent light-intensity ambulation can result in sizeable reductions in whole body energy expenditure[67] which, over time, could contribute to negative daily energy balance and subsequent weight gain.[68]

Sedentary behaviors, particularly TV viewing and other screen-based activities, may promote obesity and weight gain through increased energy intake, specifically via increased snacking behavior.[69,70] This hypothesis is supported by qualitative evidence from consumer surveys[71] indicating that most adults consume snack foods in front of the TV and also evidence from experimental studies[69,72] that show intake of high-energy snack foods is associated with TV viewing time. Additional work is required in this area to elucidate the exact pathophysiology of sedentary time with respect to the relationships with health outcomes.

Limitations of Measurement Techniques

The majority of studies included in this review utilized a self-reported measure of sedentary behavior. An inherent limitation of such measures is they may not characterize accurately the level of exposure from sedentary behavior causing deleterious health outcomes. The use of device measures of sedentary time (i.e., accelerometers) eliminates subject recall bias, allowing for a more accurate interpretation of results. However, only three studies to date have employed the use of device measures[41,54,55] when investigating prospective relationships with health outcomes. Encouragingly, one study[41] did include a self-reported measure (time spent watching TV and videos) and reported similar findings with respect to the absence of a relationship with insulin resistance. Additional studies using objective measures are needed to confirm the validity of prospective relationships based on self-reported measures of sedentary behavior.

Of the 46 studies in the review that utilized a self-reported measure, 11 used a global measure of total sitting time (9 studies exclusively). Most focused on leisure-time sedentary behaviors, specifically self-reported TV viewing time. Several of the studies also included a measure of sitting performed outside of the home (i.e., at work/when driving) and/or sitting performed at home not related to screen time (i.e., reading, at a desk).[37,47,48,52]

Although TV viewing may be the single most common sedentary behavior adults engage in,[73] for many adults, this particular behavior may occupy only a small proportion of the waking day. On average, most adults spend 7–10 hours per day in sedentary behavior,[66,74] with workplace sitting often occupying the large majority of this time.[75] The utility of a measure that assesses sedentary (sitting) behavior across the whole waking day and not exclusively during specific behaviors (i.e., TV viewing/video time) has been highlighted in the study by Gierach et al.[15] Both TV/video time and sitting time (hours/day) were associated deleteriously with incident endometrial cancer in women in the study. However, only the association with sitting time remained significant after further adjusting for BMI of the women. This suggests that engaging in sedentary behavior across the waking day not just during specific behaviors may be the most important predictor of the adverse impact of sedentary behavior on health outcomes.

Implications and Future Directions

To date, there have been only three longitudinal studies[41,54,55] published since 2006 that have measured sedentary time objectively (device-measured) and investigated the relationship with health outcomes. These studies have been confined to relationships with insulin

resistance and measures of obesity. Future prospective studies that employ objective measures of sedentary behavior are required to elucidate the impact of high levels of sedentary behavior on premature mortality risk and other health outcomes. Such studies are also necessary to confirm cross-sectional findings that device-measured sedentary time is associated with increased cardio-metabolic risk.[66] To allow comparisons among future prospective studies, a standardized approach to objectively measuring sedentary time using devices (i.e., accelerometers) should also be established.

Prospective studies investigating health outcomes in relation to non-leisure-time sedentary behaviors (specifically occupational and transportation sitting time) are also warranted given the cross-sectional evidence showing that occupational sitting is associated detrimentally with obesity/weight gain[76,77] and recent findings by Warren et al. showing time spent sitting for travel (specifically riding in a car) independently is associated with increased CVD mortality risk in adults.[47]

In addition to gathering new evidence from prospective studies, the immediate focus of future sedentary behavior research should also be directed toward experimental studies and intervention trials. Presently, no dose response studies have been conducted in adults investigating manipulations in sedentary time on metabolic biomarkers. Further, to our knowledge, only one study has investigated the feasibility and impact on health outcomes of reducing sedentary behaviors, specifically TV viewing time, in an adult population.[78] Evidence provided by future experimental studies and intervention trials will help inform policy decisions and develop recommendations and guidelines around what level of sedentary behavior confers increased health risks in adults.[79]

Findings from this review suggest there is a growing body of evidence to indicate that time spent in sedentary behavior may lead to poor health outcomes in adults and that these may be independent of physical activity. However, inconsistencies in associations when adjusting for BMI and limitations of self-reported measures indicate that additional evidence is required before concluding that sedentary behavior is a distinct risk factor for poor health outcomes. Nevertheless, the current level of evidence suggests that public health strategy might take into account how reductions in time spent sedentary could be addressed, as a novel ingredient of the physical activity and health agenda.

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Appendix

Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.amepre.2011.05.004.

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