

Sedentary behaviors and adiposity in young people: causality and conceptual model

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Abstract

Research on sedentary behavior and adiposity in youth dates back to the 1980s. Sedentary behaviors, usually screen time, can be associated with adiposity. While the association is usually small but significant, the field is complex, and results are dependent on what sedentary behaviors are assessed, and may be mediated and moderated by other behaviors.

Summary

Sedentary behaviors can be associated with adiposity but the field is complex. Results depend on the type of sedentary and other behaviors being assessed.

Key Points

- Sedentary behavior – sitting time – has long been thought to be a risk factor for pediatric obesity, especially through TV and other screen viewing, with claims made for clear and causal links.
- A closer look at the literature reveals a complex picture of statistically significant but small associations for screen time and adiposity in youth, but very small or no associations for total sedentary time assessed with accelerometers.
- Current evidence does not support a causal association.
- Results concerning obesity may depend on a variety of mediating, moderating and confounding factors, including light and moderate-to-vigorous physical activity, diet, and sleep.
- Reducing sedentary behavior in youth is probably sensible, but we propose that the field is more complex than sometimes recognized.

Key Words: causality, obesity, screen time, sitting time, TV viewing.

INTRODUCTION

1
2 Over the past decade or so, there has been a substantial increase in research
3
4 focused on what has been termed 'sedentary behaviors'. Unlike the common use of
5
6 the term 'sedentary' to mean physically inactive, behavioral scientists have been
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8 more precise and adopted the term to reflect seated or reclining postures that have
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10 low energy expenditure and are performed during waking hours (1, 2). This reflects,
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12 in practice, time spent sitting and it sets itself apart from 'lack of movement or
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14 exercise'.
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19 Morris et al's (3) analysis of seated London bus drivers and active ticket
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21 collectors over 60 years ago could be seen as the first study concerning the health
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23 effects of sitting. However, the outcomes of that study focused on the ~~active~~-ticket
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25 collectors and the health benefits of a physically active occupation. This meant that
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27 the health impacts of sitting were largely ignored, and this continued for several
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29 decades. However, in the 1980s, studies emerged on the health effects of leisure-
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31 time sitting in the form of television (TV) viewing. Research on sedentary behavior,
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33 either alone or alongside physical activity, then developed at pace from the early
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35 2000s with a focus on all phases of the behavioral epidemiology framework:
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37 measurement, health outcomes, correlates, interventions, and translation, with both
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39 young people and adults (e.g., 4, 5).
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46 A great deal of the literature has focused on health outcomes associated with
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48 different amounts of exposure to sedentary behaviors. Initially, research focused on
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50 health outcomes of TV viewing, then expanded to include 'screen time' (TV viewing,
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52 computer use and electronic games) and, with the advent of wearable technology,
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54 total 'sitting time' across the day or in certain settings (e.g. at work). ~~Other~~ Additional
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56 sedentary behaviors, such as reading and other sedentary hobbies (e.g. board
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1 games, jigsaws, art, etc), have been much less frequently investigated, while studies
2 on sitting for transportation, particularly in cars, is expanding, mainly for adults (6).
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4 The health outcomes investigated, usually from epidemiological studies, have
5 included all-cause mortality, cardiovascular disease, cardio-metabolic health
6 (including diabetes and metabolic syndrome), and obesity. Emerging outcomes
7 include cancer and psychological well-being (7). The most prolific area of coverage
8 is that for weight status and obesity, and include the early studies on TV viewing in
9 children (8). Our research over the past two decades has led to the hypothesis that
10 *'sedentary behaviors in young people can be positively associated with adiposity, but*
11 *the association is small, complex, dependent on what sedentary behaviors are*
12 *assessed, and may be mediated by other behaviors'*. Given the continued popular
13 and scientific interest in weight status and adiposity, and the volume of literature on
14 this topic in the context of sedentary behavior, we focus on this area of research in
15 the present paper.
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33 **EVIDENCE FOR AN ASSOCIATION BETWEEN SEDENTARY BEHAVIOR AND** 34 **ADIPOSIY** 35 36 37

38 Views expressed in the literature concerning whether an association exists
39 between sedentary behaviors and adiposity have varied and seem to reflect how
40 authors interpret the data. One of the first papers investigating health outcomes of
41 the most prevalent leisure-time sedentary behavior - TV viewing - was published in
42 1985 by Dietz and Gortmaker (8). Drawing on data from a large national data set of
43 over 6,500 children, they concluded that a small association did exist with adiposity
44 and fulfilled criteria "necessary to establish a causal association" (p. 811). Data from
45 New Zealand showed that hours of TV viewing in childhood were predictive of adult
46 adiposity some 10 years later (9). More recently, a very large international study of
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over 77,000 children and 207,000 adolescents from 54 countries concluded that a positive association exists between TV viewing and body mass index (BMI) (10). The strength of association was small to moderate, and stronger in females than males. For example, comparing adolescent males watching less than one hour/day of TV with those watching five or more hours, the latter had an increased BMI of only 0.16. But the difference in children was 0.36. Results showed great variability in data between countries for both TV viewing and BMI. Confounding by **maturational status** age may have influenced these results as BMI Z-scores were not analyzed (BMI Z-scores express the anthropometric value as a number of standard deviations, or Z-scores, below or above the reference mean or median value and accounts for age and sex).

National position and expert statements have also supported the view that sedentary behavior - mainly screen time - is a risk factor for greater adiposity. For example, over 20 years ago, the Australian College of Paediatrics (11) stated that “television has been implicated as a direct cause of obesity” (p. 7), and a Scientific Roundtable of the American College of Sports Medicine in 1998 concluded that obesity was ‘directly related’ to the volume of TV viewing (12). The latter statement could be interpreted as obesity leading to more TV viewing - the ‘reverse causality’ argument (see later). National guidelines, recommending reductions in sedentary time to no more than 2 hours/day of recreational screen time, now exist in many countries, although it should be noted that these are not focussed just on obesity as a possible negative outcome of high screen time.

In contrast to the statements just highlighted, there are numerous studies and reviews that have expressed a more cautious view about how and whether sedentary behavior is associated with adiposity. We conducted the first meta-

1 analysis concerning both TV and video/computer game use and associations with
2 body fatness and showed small ($r=0.066$), but significant, associations (13). We
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4 questioned whether such an association was practically meaningful, although this
5
6 was challenged by others (14). Similar to the more cautious view we expressed in
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8 Marshall et al.'s meta-analysis (13), in our systematic review of the correlates of TV
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10 viewing in young people we concluded that TV viewing was associated with body
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12 weight but not body fatness (4).
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17 Studies using estimates of children's total sedentary time are also
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19 inconclusive. In a large international sample of 9-11 year old children assessed using
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21 accelerometers (15), sedentary time was shown to have a small association with
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23 obesity across the whole sample, but was only significant in five of 12 countries.
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25 Moreover, this association was not independent of moderate-to-vigorous physical
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27 activity (MVPA). Similarly, a large multi-national cohort study of accelerometer-
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29 assessed sedentary time showed no significant association with waist circumference
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31 in children and adolescents (16). In contrast, analysis of adolescents' accelerometer
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33 data from the 2003/04 and 2005/06 US National Health and Nutrition Examination
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35 Survey (NHANES) found that for every hour spent sedentary, BMI Z-scores
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37 decreased by 1.33 units. However, after adjusting for MVPA this relationship was no
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39 longer significant (17).
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47 Given the inconsistent findings reported in the literature and, more
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49 importantly, the diverse interpretation of such data, we conducted a review of 29
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51 systematic reviews concerning sedentary behavior and adiposity in youth (18).
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53 Specifically, we addressed observational and experimental studies, through the
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55 assessment of both self-reported behaviors and wearable technology. A summary of
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57 conclusions from this analysis is presented in Table 1. Overall, it seems that
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1 evidence of associations between sedentary behavior and adiposity is most
2 consistent for cross-sectional studies of TV viewing (screen-time). The longitudinal
3 and experimental evidence is inconsistent (ranges from no evidence to modest and
4 strong evidence) and appears dependent on the outcome and sedentary behavior
5 measures assessed.
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12 INSERT TABLE 1 HERE
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14 ANALYSIS OF CAUSALITY 15

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17 Given the diversity of findings reported in our review of reviews (18), but also
18 the conclusion that associations between sedentary behavior and adiposity in youth
19 have been shown, a more robust analysis can be derived from assessing the nature
20 of this relationship against the 'Bradford Hill causality criteria' (19). Hill proposed a
21 number of criteria on which to judge whether an exposure is causally related to a
22 health outcome. These include strength of association, consistency, specificity,
23 temporality, coherence and biological plausibility, dose-response, and experimental
24 evidence. The conclusions stated by Biddle et al. (18), using these criteria, are
25 shown in Table 2. Discussion here will centre on the key factors of strength of
26 association, dose-response, experimental evidence, and coherence and biological
27 plausibility.
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44 INSERT TABLE 2 HERE
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46 Strength of Association 47

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49 From the first meta-analysis investigating TV viewing and body fatness in
50 youth we published in 2004 (13), in which we reported a small but significant
51 association ($r=0.066$), evidence has shown consistent significant associations
52 between sedentary behavior and markers of adiposity, although usually such
53 associations are small. Similar effects have been found in interventions. Prospective
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1 studies suggest an effect of almost zero for the relationship between baseline TV
2 viewing and BMI at follow-up when controlling for baseline BMI (20).
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4 It appears that there is little dispute that associations and effects for screen
5 time (but not total sedentary behavior assessed with wearable technology) on
6 adiposity in youth are significant but small. So to what extent are such values
7 clinically or practically meaningful? This has been an area of some dispute. Is the
8 glass 'half full' or 'half empty'? Key issues in this debate, and which may reflect a
9 'glass half full' approach, concern: a) small effects in large populations; b) the
10 measurement of sedentary behavior; c). the lack of intervention fidelity; and d) the
11 tracking of sedentary behavior and consequences for health in adulthood.
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24 All young people engage in sedentary behavior, and nearly all watch some
25 television or engage in some form of recreational screen time. This means that small
26 effects on adiposity across a large population may have significant public health
27 effects. Moreover, as argued by Hancox and Poulton (14), the association between
28 TV viewing and adiposity may be attenuated by restriction in the range of values for
29 TV viewing. They argue that very few young people do not watch any television,
30 hence associations are calculated from restricted values (i.e., from more than zero).
31 While this might lead to an under-estimation of the true strength of association
32 between sedentary behavior and adiposity, trend data suggest declines in the
33 percentage of youth in the US watching more than 3 hours of TV a day (from 43% in
34 1999 to 35% in 2007) (21), which may also make it difficult for longitudinal studies to
35 show associations. This is against a backdrop of overall increases in 'media
36 exposure' from 37 hours per week in the early 1960s to as much as 75 hours per
37 week in 2009 (22), the latter figure likely inflated due to multi-tasking. But much of
38 this increase will be attributable to electronic media. These changes in exposures to
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1 screen use make it difficult for studies to accurately determine the strength of
2 association between sedentary behavior and adiposity in young people.
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4 Measurement issues may also influence the inconsistency of associations,
5 including the inability to differentiate sitting from standing using some wearable
6 technology (23), and the difficulty of recalling long bouts of sitting and breaks in
7 sitting. Discrete behaviors, such as TV viewing, may be more easily and accurately
8 recalled and hence allow for more consistent associations to be detected with less
9 measurement error.
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18 The weak effects of interventions may partly be related to poor intervention
19 fidelity. In other words, the interventions may not have been delivered as intended
20 (see section on 'Experimental Evidence').
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26 Sedentary behavior has been found to track into adulthood-(24). The strength
27 of this is moderate, and slightly larger for TV viewing than other measures-(24). It is
28 broadly comparable to the tracking of physical activity_(24). Moreover, there is some
29 evidence for increased risk of obesity in adulthood from sedentary behavior in
30 childhood and adolescence (25). It is plausible, therefore, that the small associations
31 found for sedentary behavior and adiposity in young people may have implications
32 for health in adulthood. We have shown cross-sectional associations between TV
33 viewing time and inflammatory and endothelial biomarkers (after adjusting for waist
34 circumference, diet and MVPA) in 8-9 year olds (26). The associations were modest
35 (for every hour/week of TV viewing, 4.4% and 0.6% greater C-reactive protein [CRP]
36 and soluble vascular adhesion molecule 1 [sVCAM-1], respectively). However, the
37 tracking of low-grade inflammation from childhood to adulthood and relationships
38 between markers of inflammation and endothelial function with atherosclerotic
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1 lesions (27) support the findings from Biddle et al.'s (18) review of reviews, that
2 elevated biomarkers early in life may be indicative of cardiometabolic risk later in life.
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4 These arguments suggest that it may not be appropriate to dismiss the small
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6 associations as clinically or practically irrelevant, although further work is needed on
7
8 this. In conclusion, evidence for strength of association between TV viewing and
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10 adiposity is consistent but weak (i.e. associations are usually small), while
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12 associations between accelerometer-measured sedentary time and adiposity are
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14 inconsistent, though often null, although fewer studies exist here.
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18 **Dose-Response**

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20 A dose-response relationship – what Hill (19) referred to as a 'biological
21
22 gradient' – between sedentary behavior and adiposity in youth does appear to exist
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24 (see 18, and Table 2). However, this has not been tested extensively and estimates
25
26 vary. One meta-analysis of 10 cross-sectional studies showed a pooled odds ratio of
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28 1.13 for obesity risk per hour of TV viewing (28). The graph provided in the review
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30 paper suggested a linear relationship. But dose-response curves can take many
31
32 shapes and it is plausible that obesity will be related to sedentary behavior only at
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34 higher levels of exposure. Given that studies vary in the way they assess and
35
36 categorize sedentary time, this is not easy to test with precision.
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43 It is often recommended by government health agencies that young people
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45 take part in less than 2 hours of recreational screen time daily for a variety of
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47 physical and mental health benefits, not just obesity prevention and management
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49 (11). The first data to test for dose-response in this field was from the 1980s and
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51 showed that children watching TV less than 2 hours/day had the lowest prevalence
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53 of obesity, but a clear dose-response curve was not evident. On the other hand, a
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55 dose-response curve was seen more clearly for adolescents (8). The uneven
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1 distribution of TV viewing prevalence may attenuate effects on obesity or restrict the
2 possibility of a clear dose-response curve being shown. Moreover, the use of
3 screens is changing rapidly, with declines in TV viewing and increases in the use of
4 other screens (21, 22), not all of which will be engaged in through sitting. In
5 conclusion, there does appear to be a small dose-response effect for TV viewing and
6 adiposity in youth. However, caution needs to be expressed as true dose-response
7 effects can only be tested with longitudinal data. Our conclusions are also drawn
8 from data that include cross-sectional designs. In such studies, conclusions can only
9 be made about the degree to which screen time and adiposity are graded in their
10 relationship.

23 **Experimental Evidence**

24 The review by De Mattia et al. (29) highlights the inconsistent interpretation
25 and reporting in relation to the impact of experimental studies to reduce sedentary
26 behavior on children's and adolescents' weight status. In their abstract they stated
27 that interventions "reduced sedentary behavior and improved weight indices. An
28 emphasis on decreasing sedentary behaviors is an effective intervention to decrease
29 sedentary behaviors and control weight in children and adolescents" (p. 69). This
30 reflects the 'glass half full' argument. Yet in their discussion they conclude that "The
31 magnitude of weight parameters is modest and is difficult to interpret" (p. 79) – 'glass
32 half empty'. One reason they say this is that maturational factors are often not
33 accounted for, ~~with BMI Z-scores infrequently used.~~

34 Not surprisingly, more substantial decreases in BMI may be achieved through
35 reductions in sedentary behavior among obese children. A recent meta-analysis (30)
36 showed a small, but significant, change in BMI from interventions involving sedentary
37 behavior reduction (-.158 BMI), which was higher in overweight and obese
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populations (-.493 BMI). A key issue in interpreting such findings is to consider what active behaviors are engaged in to substitute for reductions in sitting time, and to determine whether diet and sleep were also affected. This is discussed in more detail later. Moreover, interventions have rarely targeted just sedentary time, hence making interpretation of intervention effects difficult.

While sedentary behavior reduction may assist weight control, the evidence is currently weak. One reason for this conclusion is that the success of interventions in changing sedentary behavior in young people has been modest (5). Our meta-analysis of 17 studies showed a small but significant effect in changing behavior (Hedges' $g=-0.192$), and subsequent analyses have yielded similar results (31). However, it is noteworthy that in the meta-analysis by Kamath et al. (32), sedentary behavior interventions for young people, showed a small but significant effect size (ES=-0.29), compared to physical activity (ES=0.12) and healthy dietary change (ES=0.00) interventions. However, it is not possible to conclude whether interventions were largely delivered as intended or whether intervention fidelity was weak. More process evaluations of interventions are required.

Our review of reviews suggested that the experimental evidence is still weak in showing effects for reductions in adiposity (18), but this could be due to only modest effects from interventions for actual behavior change. Obese young people may see stronger effects for adiposity from reductions in sedentary behavior (30).

Coherence and Biological Plausibility

Sedentary behaviors, by definition, involve low energy expenditure, therefore it is entirely plausible, and coherent with current knowledge, that they be associated with markers of adiposity. However, evidence also exists showing that sedentary

1 behaviors need to be understood in the context of other, potentially co-existing,
2 behaviors. The main behaviors of interest are physical activity, diet, and sleep.
3

4 Physical activity occurs on a movement (intensity) continuum ranging from
5 sleep and sedentary behavior, to light, moderate, and vigorous physical activity. Two
6 important implications stem from this. First, any change to sedentary behavior must
7 be reflected in a change in at least one of the other behaviors or intensities across a
8 24-hour period (33). Second, any reporting of associations between sedentary
9 behavior and health outcomes (e.g. adiposity) must account for other relevant
10 confounding or potentially mediating behaviors (e.g. dietary intake).
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12 It has been shown that MVPA is only weakly inversely associated with
13 sedentary behavior (34), suggesting that the two behaviors can co-exist. However,
14 given that any reduction in sitting time, during waking hours, will result in an increase
15 in movement, it is light-intensity physical activity (LIPA) that is most likely to increase
16 rather than MVPA. Some of this substitution effect from sedentary behavior will be
17 into 'low' LIPA, such as standing, which in adults has not been shown to change
18 energy expenditure much in the short term (35). While 'low' LIPA has been found to
19 be beneficially associated with cardiometabolic biomarkers in US youth (36), few
20 studies have explored relationships with adiposity in younger age groups. A
21 systematic review of the impact of height adjustable desks on children's sedentary
22 behavior and physical activity found two studies that reported small increases in
23 energy expenditure, and four out of the six studies that examined changes in
24 [stepsping](#) reported small to moderate effects (37). Evidence is needed to further
25 explore the longer-term health effects of height-adjustable desks, and to identify
26 what intensities of activity are substituting for reductions in sitting time.
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If sitting time is reduced and replaced with more ‘high’ LIPA (e.g. incidental movement, light walking), and certainly with moderate physical activity, then energy expenditure will increase. However, profiling of participants shows that sedentary time can co-exist with MVPA (38). This means that some individuals will have high sedentary behavior and high MVPA, while others could have high sedentary behavior and low MVPA. Evidence exists for minimal deleterious health effects for high sedentary time among children who are also physically active at a high level (39).

The second important behavior to take into account is diet. Like physical activity, dietary intake is a modifiable health behavior that is independently associated with health outcomes such as adiposity. Dietary intake encompasses a diverse array of foods and food items that make categorising ‘diet’ as a whole extremely difficult. In terms of sedentary behavior, and its relationship to diet, researchers tend to focus on elements of a less healthy diet such as lower fruit and vegetable consumption, higher consumption of energy-dense snacks, drinks, and fast foods, and higher total energy intake (40). Our own research has shown that sedentary behavior, in particular screen time, is associated with a higher consumption of energy-dense snack foods and sugar-sweetened drinks, and lower consumption of fruit and vegetables in young people (41).

Some of the plausible explanations for such an association in young people include that during time spent sitting in front of the TV and computers, young people are exposed to numerous advertisements (most often for ‘junk foods’) that can influence the type of food desired, requested and consumed (42). Furthermore, screen viewing behaviors may cause distraction resulting in a lack of awareness of actual food consumption or overlooking food cues, which may lead to

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overconsumption and increased energy intake (43). Early research suggests that young people may associate TV viewing with eating from a young age if, for example, parents place their children in front of the TV with a snack or a meal while they do household chores (44).

The evidence for an association between sedentary behavior and unhealthy diet suggests that dietary intake may play a role in the relationship between sedentary behavior and weight-related health outcomes. However, the mediating role of dietary intake in the associations between sedentary behaviors and adiposity has rarely been examined in young people. We recently reviewed 21 studies exploring whether the associations between various sedentary behaviors and cardiometabolic risk markers are independent of dietary intake in adolescents. Results suggested that significant positive associations exist between TV viewing, screen time and self-reported overall sedentary behavior with markers of adiposity, independent of dietary intake (45). However, only one study explored whether dietary intake played a mediating role. Recent analyses of the NHANES adolescent data found no evidence for dietary intake mediating the relationship between TV viewing and BMI Z-scores (46). There was, however, a partial mediation of sugar-sweetened beverages (8.7%) and fruit and vegetables (4.1%) between TV viewing and metabolic syndrome (incorporating waist circumference, blood pressure, blood glucose and insulin, and serum lipids). Limitations of many of these studies included the inconsistent dietary categories explored, and none of the studies included measures of dietary intake during participation in the sedentary behavior.

A cross-sectional study of over 1000 Canadian and US 10-year olds showed that having a TV in their bedroom was associated with greater TV use and adiposity (47). However, this was not mediated by diet or sleep. This indicates that if diet is

important in the relationship between screen viewing and adiposity, it may not necessarily be so for all screen locations. Moreover, s

Studies exploring the mediating role of dietary intake concurrent with sedentary behavior are needed.

The third important potential mediator in a relationship between sedentary behavior and adiposity is sleep. Adolescents have shown a decline in sleep duration in recent decades and short sleep duration has been associated with weight gain (48). In a recent review (49), young people with high physical activity, high sleep, and low sedentary behavior had healthier profiles, including less adiposity. It is thought that screen time disrupts sleep and may be associated with increased consumption of food late in the evening. Sleep disruption could be associated with higher fatigue and thereby less physical activity, and more screen time late at night, with associated exposure to light. While more research is needed, the combined effects of high levels of sedentary behavior and reduced sleep, alongside physical activity and diet, require further investigation in the etiology of pediatric obesity. Evidence to date points to the need to facilitate 8-10 hours of sleep per night for adolescents (48), and studies investigating sedentary behavior and adiposity that account for sleep hygiene are needed.

In addition to considering the role of physical activity, diet, and sleep, to better understand the coherence of the relationship between sedentary behavior and adiposity in youth it is also necessary to recognize the likelihood of a bi-directional association. This so-called 'reverse causality' argument suggests that in some cases, individuals who have greater adiposity will engage in higher levels of sedentary behavior. The 'reverse causality' hypothesis has rarely been properly tested, but is plausible. While there are studies showing some direction of effect from longitudinal studies for sedentary behavior to precede adiposity (9), a great deal

1 more work is required on the direction of association. Reverse causality may explain
2 why stronger cross-sectional than longitudinal associations are often found. For now,
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4 with young people, we need to assume that a bi-directional 'effect' is both plausible
5 and, for some, likely.
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9 In conclusion, while the mediating or confounding roles that physical activity,
10 dietary intake, sleep and reverse causality play in the relationship between sedentary
11 behavior and adiposity in youth is not entirely clear, there is moderate evidence in
12 support of coherence and biological plausibility for the association between
13 sedentary behaviors and adiposity in youth.
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21 **TOWARDS A CONCEPTUAL MODEL**

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23 The link between sedentary behavior and adiposity in young people has been
24 studied extensively for over 30 years. Much of this research has centred on screen
25 time, and often TV viewing time. There is clearly diverse opinion concerning the
26 nature and extent of any association. As intimated earlier, it reflects a debate
27 between the 'glass half full' argument (there is a small but meaningful association)
28 and 'glass half empty' argument (the association is small or close to zero, and not
29 practically or clinically significant). It could also be argued that neither position is
30 wholly 'correct' and rather a more appropriate conclusion is that 'it's complex' (50).
31 One only has to view the 'spaghetti diagram' depicting the multitude of influences on
32 obesity displayed in the UK Foresight Report (51) to realize that we are not dealing
33 with a simple issue. As Rutter (50) argues, obesity is complex rather than
34 complicated: "Research within the biomedical paradigm tends to focus on specific
35 topics such as dietary behavior and physical activity, psychological drivers, or
36 genetic influences; the wider issue of obesity is then constructed from these
37 elements. Obesity is thus treated as a complicated issue, not a complex one" (p.
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1 746). Perhaps we have fallen into the 'trap' of taking only a biomedical view of
2 sedentary behavior. We can look at sedentary behaviors in relative isolation, yet this
3 ignores the complexity of: a) a multitude of different sedentary behaviors; b) many
4 other behaviors co-existing with sedentary behaviors; and c) multiple biological,
5 genetic, social, cultural, psychological and environmental influences on obesity
6 across the domains of physical activity and diet. Sleep and other factors are also
7 implicated. Moreover, single sedentary behaviors, such as TV viewing, while being
8 important in their own right, may not be good markers of total sedentary time (52).
9

10 The complexity can partly be summarized by the factors identified in Table 3.
11 As argued in this paper, sedentary behaviors may be associated with adiposity but
12 this could be confounded by levels of LIPA, MVPA, dietary patterns, and sleep.
13 Associations may also be bi-directional. Moreover, drivers of sedentary behavior
14 may be somewhat context dependent (home, school, travel), and each context may
15 differ in the degree to which sitting is a personal choice, and has environmental and
16 social constraints. In addition, a number of other potential moderators, mediators,
17 and confounders could exist, such as maturational status in adolescence, and socio-
18 economic status (SES). The latter has been linked to both obesity and sedentary
19 behavior (4).
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INSERT TABLE 3 HERE

66 In addition to Table 3, we have provided a simplified conceptual model in
67 Figure 1. Children and adolescents engage in multiple sedentary behaviors. The
68 areas that have received the most attention include: i) self-reported screen time
69 (including TV viewing); and ii) total sedentary time, usually assessed with wearable
70 technology. From our assessment of review-level data, total sedentary time
71

1 assessed with accelerometers is largely uncorrelated with markers of adiposity in
2 youth (18).
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5 INSERT FIGURE 1 HERE
6

7 Screen time – the most studied cluster of sedentary behaviors – has shown
8 some variability in its association with adiposity, as discussed. Associations vary
9 from ‘strong’ to near zero. However, our analysis from a review of reviews (18)
10 suggests that there is insufficient evidence to conclude that this association is
11 causal. As shown in Figure 1, screen time associations with adiposity may be
12 mediated by co-existing behaviors of LIPA, MVPA, diet, and sleep, although work is
13 required to further examine these relationships~~a great deal work is required on these~~
14 ~~factors~~. For example, while evidence on the link between screen time and diet has
15 been shown, the link with adiposity is less clear (45). Moreover, these factors may be
16 moderated, or even confounded, by maturational status in adolescence, SES, other
17 co-existing behaviors, and the context that different sedentary behaviors take place
18 in. The bi-directional nature of the association between sedentary behavior and
19 adiposity (‘reverse causality’) is also important to consider, as discussed. Contextual
20 differences are shown in Table 3.
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41 CONCLUSION AND SUMMARY

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43 Evidence for a relationship between screen time, including TV viewing, and
44 adiposity in children and adolescents is often statistically significant but small in
45 magnitude. Studies assessing total sedentary time with wearable technology
46 (accelerometers) tend to show smaller, and sometimes, no effects. Arguments about
47 the practical significance of these findings reflect the difference between ‘glass half
48 full’ and ‘glass half empty’ perceptions. Whatever the interpretation concerning
49 adiposity, there may be important public health benefits for reducing recreational
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1 screen time in youth for many reasons, many beyond just obesity, and guidelines
2 that suggest reductions are sensible.
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5 This area of research is complex. Many interpretations of the study data fail to
6
7 recognise this and future research needs to account for likely mediators, moderators,
8
9 and confounders, as well as the bi-directional nature of the relationship. We have
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11 tried to show this in Figure 1. The diagram is not a definitive statement summarising
12
13 the evidence. It provides a schematic heuristic and an overview of possibilities.
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15 Moreover, rapid changes to screen technologies make it difficult to capture
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17 sedentary behavior exposures of young generations. This is a 'moveable feast' and
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19 is a challenge for researchers.
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Figure caption

Figure 1. Conceptual overview of possible associations and influencing factors between sedentary behaviors and adiposity in youth.

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Table 1. Summary of key findings from a review of 29 systematic reviews concerning sedentary behavior and adiposity in young people reported by Biddle et al. (17).

Types of study	Summary conclusions	Comments
Observational: cross-sectional	<ul style="list-style-type: none"> • Evidence for small but significant associations for TV viewing and screen time with adiposity • Smaller or no association when assessed using accelerometers 	<ul style="list-style-type: none"> • Evidence less clear in relation to computer use
Observational: longitudinal	<ul style="list-style-type: none"> • Mixed evidence for associations ranging from 'no evidence' to 'strong' evidence, the latter for screen time and BMI, and TV with overweight/obesity • No association when assessed with accelerometer 	<ul style="list-style-type: none"> • Results seem dependent on nature of the outcome and sedentary behavior measures assessed
Experimental	<ul style="list-style-type: none"> • Weak effects on adiposity from interventions to reduce sedentary behavior • Effects greater in more obese samples 	<ul style="list-style-type: none"> • 4/10 reviews showed null or inconsistent effects • Interventions tend to show only small changes in behavior • Many interventions targeted changes to additional behaviors, making it difficult to isolate effects of reducing sedentary behavior alone

Table 2. Summary of judgements concerning the Bradford Hill criteria for causality in assessing sedentary behavior and adiposity in youth, as reported by Biddle et al. (17).

Criteria	EVIDENCE			
	No	Weak	Moderate	Yes
Strength of association		√		
Consistency		√	√	
Specificity	√			
Temporality		√		
Coherence and biological plausibility			√	
Dose-response			√	√
Experimental evidence		√		

Table 3. Multiple contexts, sedentary behaviors, co-behaviors, and possible influences.

	SEDENTARY BEHAVIOR CONTEXT		
	Home	School	Travel
	<i>TV, computers, other screens (e.g. phones), hobbies (e.g. reading), eating meals</i>	<i>Sitting at a desk</i>	<i>Sitting in a car</i>
Do SBs displace moderate-to-vigorous physical activity?	Some evidence for small association; larger at weekends and in immediate after-school period.	Unlikely, although classroom standing and activity breaks are feasible but likely to result in increases in LIPA rather than MVPA.	Yes. Active travel will be a direct replacement for sitting in a car.
Are SBs linked to dietary patterns and adiposity?	Screen use (mainly TV) associated with less healthy diet. But systematic review suggests a lack of evidence that sedentary behavior and adiposity are mediated by diet.	Unlikely	No evidence
Could SBs be linked to adiposity through less sleep?	Possibly through sleep disruption with late night screen time, light exposure through screens, and increased food consumption	No evidence	Unlikely

	if sleep is reduced. More data required.		
Do SBs involve personal choice?	Yes	No	Potentially yes, although many children have little actual choice due to parental preferences/concerns.
Are there environmental constraints?	Some. Family home often set up for sitting as default, plus access to TV and other screens. TV in bedroom associated with greater usage by young people.	Yes. School desks generally only accommodate sitting.	Yes. Influenced by distances, routes, safety, active/public transport options.
Are there social constraints?	Yes through parental expectations and social norms for sitting.	Yes. Expectation is to sit and work.	Some. Car often seen as default option for travel. Parents express safety concerns about active travel.

Figure

