Title: Australia and other nations are failing to meet sedentary behaviour guidelines for children: implications and a way forward

Running Title: Failure to meet sedentary guidelines for children

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Abstract (200 words)

Background: Australia has joined a growing number of nations which have evaluated the physical activity and sedentary behaviour status of their children. Australia received a 'D minus' in the first Active Healthy Kids Australia Physical Activity Report Card.

Methods: An expert subgroup of the Australian Report Card Research Working Group iteratively reviewed available evidence to answer three questions: 1) What are the main sedentary behaviours of children?, 2) What are the potential mechanisms for sedentary behaviour to impact on child health and development? and, 3) What are the effects of different types of sedentary behaviours on child health and development?

Results: Neither sedentary time nor screen time are homogeneous activities likely to result in homogenous effects. There are several mechanisms by which various sedentary behaviours may positively or negatively affect cardiometabolic, neuro-musculoskeletal, and psycho-social health, though the strength of evidence varies. National surveillance systems, and mechanistic, longitudinal and experimental studies are needed for Australia and other nations to improve their grade.

Conclusions: Despite limitations, available evidence is sufficiently convincing that the total exposure and pattern of exposure to sedentary behaviours are critical to the healthy growth, development and wellbeing of children. Nations therefore need strategies to address these common behaviours.

Australia and other nations are failing to meet sedentary behaviour guidelines for children

In May 2014, 15 countries gathered in Toronto, Canada for the Global Summit on Physical Activity of Children in response to international concern over the physical inactivity of the world's children. Using expert consensus panels, countries reviewed their respective available data and weighed the evidence to assign a grade for nine core indicators in national Physical Activity Report Cards. The core indicators were related to individual behaviours that contributed to overall physical activity levels, as well as sources of influence and strategies and investments. One of the core behavioural indicators was sedentary behaviour which was operationalised as the proportion of children and young people meeting the recommended national screen time guidelines. For Australia, this is spending no more than one hour per day for 2-4 year olds and less than two hours per day for 5-17 year olds viewing an electronic screen for leisure purposes .[1] Currently there are no national data for children less than 2 years of age to determine what percentage are complying with the national guideline of no screen time.

Australia received a grade of 'D minus(-)' for sedentary behaviours, with only 29 % of 5 to 17 year olds meeting screen time recommendations.[2,3] Fewer Australian teenagers met the recommendations (19 %of 15-17 year olds) than younger school children (41 % of 5-8 year-olds and 24% of 9-14 year-olds) or pre-schoolers (26 % of 2 -4 year-olds).[3] Australia is not alone, with four other countries rated below Australia with a 'Fail' and four more with a 'D' in sedentary behaviour. The highest grade achieved was a 'B', by Ghana and Kenya, followed by New Zealand and Ireland which both received grades of 'C' (See Table 1). While the metrics used to assign grades varied between countries, the grades assigned raise the question: *What can countries do to improve their grades?*

Australia's sedentary behaviour grade was based on the percentage of children meeting the recommendations for daily screen time, as it generally was for other nations (though the exact definitions varied). The Active Healthy Kids Australia Physical Activity Report Card focused on screen time sedentary behaviour for a number of reasons. Firstly, national guidelines recommend a dose specifically for screen-based sedentary behaviours[1] and the best nationally representative data available in Australia were for compliance with screen time guidelines rather than all sedentary behaviours. Secondly, the Research Working Group (24 experts in the field of physical activity and health from around Australia who evaluated the evidence and assigned a grade by consensus) had more confidence in reported screen time than other self- or proxy- report measures of sedentary behaviours.[4] Thirdly, there was stronger evidence that screen time, particularly television (TV) watching, was associated with detrimental outcomes (see Question 3 section for further details [5]). However, basing the grade solely on meeting screen time guidelines is a limitation for multiple reasons: 1) much of childhood sedentary behaviour is not screen-based; 2) overall sedentary behaviour, in addition to screen time, potentially has detrimental effects;[6,7] and 3) screen time itself is varied and changing rapidly.

Methods approach

The following is a discussion of key evidence that resulted from a critical review by an expert subgroup of the Australian Report Card Research Working Group The Research Working Group had been collecting and evaluating literature and data related to the Report Card generation. To conduct the present review, the first two authors conducted a further literature search of primary databases to capture recently published evidence. The critical analysis followed an iterative process by the expert sub-group where additional literature was considered and all evidence was synthesized. The experts reviewed the literature in reference to three general questions about sedentary behaviours as seen in

Figure 1. A better understanding of the answers to these three questions will help inform strategies to reduce sedentary behaviours among children and thus improve the grade.

Question 1: What are the main sedentary behaviours of children?

Sedentary behaviour is defined as any waking behaviour with a low energy expenditure (<1.5 METS) and a sitting or reclined posture[8] and is part of a spectrum of 'activity' of various energy expenditure intensities ranging from sedentary, through light (typically ≥1.5–<3 METS), to moderate (≥3–<6 METS) and vigorous (≥6 METS). Although there has been debate on the specific MET cutpoints used for children,[9] research in young children suggests that 1.5 METS is consistent with the energy cost of sedentary activities.[10] Thus each child's 24-hour day can be divided into sleep and wake 'activity', with 'activity' further divided by intensity into sedentary, light, moderate and vigorous time. The most common measures of sedentary behaviour are self-report and accelerometry, which both have limitations.[11] Self- or proxy- report questionnaires and recalls are subject to recall bias and some continue to show limited validity compared to device based or objective measures, and accelerometers do not distinguish between types of sedentary behaviours or provide context. Inclinometers have been increasingly used to measure sedentary time as they better distinguish between postures of sedentary behaviours (ie lying, sitting, standing), but still do not provide context or type of behaviour. Accelerometers can yield widely discrepant estimates of sedentary time according to device placement and analytical decisions around non-wear time, operationalisation of sleep, epoch length and intensity cut-offs. This is only a brief description of some of the issues surrounding the measurement of sedentary behaviours in children, a topic which warrants further discussion beyond this review.

Being sedentary is seen as different to not attaining recommended daily amounts of moderate to vigorous physical activity (MVPA) as a child can spend a large portion of their day in sedentary behaviour but still meet daily MVPA recommendations of at least 60 minutes.[12] Further the health effects of accumulating too little physical activity or too much sedentary time may differ, [13-15] although the research evidence in children is still building.[16-19]

The largest proportion of a child's waking day is spent in sedentary behaviour. For example, accelerometer data on Australian 10-12 year olds showed that 63 % of their waking day was spent engaged in sedentary activities, as shown in Figure 2.[20] While objective surveillance of Australian children's physical activity is limited, studies suggest that preschool-aged children,[21,22] primary school aged children[23] and young adolescents[24] spend at least 60 % of wake time in sedentary behaviours, which is consistent with data from 39 countries.[25] These data also suggest that the proportion of the waking day spent sedentary increases with age across childhood, although the evidence for young children and how sedentary behaviour tracks throughout childhood into adulthood is limited.[26]

Sedentary behaviour can be thought to occur in four main domains of children's lives – education/school/child care, transport, self care/domestic chores, and leisure/play, . For school-aged children, a main 'occupation' is that of being a student in which the majority of time at school is sedentary.[20] Educational tasks are also completed away from school, which contributes to additional sedentary time. Most Australian 4-5 year old children (85%) who are not yet in school attend preschool.[27] A recent review found estimates of screen time use during childcare ranges from 0.1 to 2.4 hours per day.[28] Sedentary transport tasks include sitting in buses, trains and cars to get to and from school and other destinations. Sedentary self-care tasks include eating and some grooming. Leisure and play sedentary behaviours include reading from a book or an electronic screen. With such a diversity of tasks and differential time spent in each task, it is likely that not all sedentary behaviours are equal in terms of their impact on healthy growth, development and wellbeing.[29,30]

Sedentary behaviours are often classified as being either based around an electronic screen or not.[23,31] Screen time sedentary behaviours were initially TV, then included video games and desktop/laptop computers and now include touch screen tablets and smart phones. Currently data on the use of new touch screen devices by children are very limited, and the development of smart devices has decoupled device and content—children no longer need a TV to watch 'TV'. Non-screen sedentary behaviours of children typically include class time at school, commuting, reading from paper, talking and eating, though with multitasking and the growing integration of technology into daily life, each of these examples could also involve screen time. Figure 3 shows nationally representative Australian data from 2007 and illustrates that total daily sitting time is high from age 9 to 17 years and is composed of around 3.5 hours of screen time and 6 hours of non-screen time.[26] Thus whilst screen time is often the focus, it does not constitute the majority of sedentary behaviour for most children.

In summary, children spend a large proportion of their waking hours in sedentary behaviours for a range of reasons. Childhood sedentary behaviour is varied in aspects potentially important to child health and development and given the high exposure and varied nature of sedentary behaviour, it is critical to understand the impact of sedentary behaviours on healthy growth, development and wellbeing.

Question 2: What are the potential mechanisms for sedentary behaviours to impact on child health and development?

There are a number of mechanisms by which sedentary behaviours may impact on child health and development, as illustrated in Figure 1.

Disruption of metabolism – Sedentary behaviours could potentially influence energy expenditure, energy intake and energy metabolism which could impact on adiposity and other cardiometabolic outcomes.

Sedentary behaviours may directly decrease energy expenditure. Prolonged low energy expenditure during sedentary behaviours could result in lower daily energy expenditure via low levels of muscle activity and thus decreased energy expenditure. Children typically have low levels of energy expenditure (<1.5 METs) during common sedentary activities.[10,32] Sedentary behaviours also may displace higher energy expenditure activities, which have clear metabolic health effects. Moderate to vigorous physical activity is known to have positive effects on cardiometabolic outcomes in children including increased myocardial function, improved cholesterol, and decreased blood pressure. [6,33] Therefore, children that spend too much time in sedentary behaviours may be in double jeopardy, as they may be impacted by the negative effects of sedentary behaviours and not benefit from the positive effects of the more vigorous activities that could have been engaged in for some of that time.

Some sedentary behaviours, or activities during sedentary behaviours, may directly increase energy intake and thus impact on cardiometabolic outcomes. For example, children consumed more calories during a meal while watching TV than while playing with computers or video games.[34] Additionally, some sedentary behaviours, or exposure to content during sedentary behaviours, may indirectly increase later energy intake. For example, increased intake of junk food may result from seeing sugar-sweetened beverage sponsorship signs whilst watching a sporting event either live or on TV, or viewing fast food advertisements during social media use.[35,36]

Prolonged sedentary behaviour can also alter energy metabolism. Laboratory studies in adults [37,38] have demonstrated changes in glucose metabolism, however a similar study in children was not able to demonstrate a similar effect.[39] In addition to changes in glucose metabolism, prolonged low energy expenditure may also result in changes in the partitioning of fat and decreased muscle protein synthesis rates [7] with effects on metabolism occurring beyond time spent in sedentary behaviours. Both the timing and patterns of sedentary behaviour may have important influences on energy metabolism.[40]

Limited neuromuscular activity – Sedentary behaviours may impact gross motor control, bone and muscle development via low levels of movement and muscle activity and/or the displacement of movement activities with appropriate loading. Lack of practice of gross motor skills could result in reduced motor capacity.[41] Forces exerted during sedentary behaviour are typically insufficient to stimulate bone growth, compared with activities such as jumping and skipping.[42,43] Muscle development similarly requires sufficient loading to stimulate growth, strength development and flexibility and sedentary behaviours may not provide sufficient stimulus,[44] compared with MVPA and strength training.[4] Some sedentary behaviours may have a positive impact on fine motor skill development, for example, drawing and playing electronic games.[45]

Prolonged, awkward postures or repetitive motions – Sedentary behaviours could have an impact on musculoskeletal outcomes via prolonged or repetitive stress on tissues. Inflammation of tendons and surrounding connective tissue can be caused by highly repetitive movements, such as video games which require frequent button activation[45] or playing a piano.[46] However, these activities may positively impact fine motor skills.[47] Joint and muscle discomfort can be caused by sustained postures, particularly when the posture is awkward (greater anti-gravitational load or near to the end of joint range of motion in one or more planes), such as writing on paper or watching a video on a smart phone or tablet held close to the body. These activities require positions near to the end range of neck flexion, which may cause neck pain.[48]

Socio-emotional experiences – Sedentary behaviours could have an impact on emotional health and social well-being via exposure to anti-social material and displacement or provision of positive social interaction.[49] Increased access to the internet adds another avenue for children to be exposed to inappropriate anti-social content and negative social interactions such as cyber-bullying.[50] Sedentary behaviours may also displace or negatively influence useful intrapersonal interactions where children learn social and life skills. Virtual social interactions do not provide all the cues available in face-to-face interactions and thus excessive virtual interaction to the exclusion or even as part of face-to-face interactions, may impede a child's social skills.[51] Similarly, other non-social non-screen sedentary behaviours, such as reading books, may have negative developmental psychosocial outcomes.[52] However sedentary behaviours such as playing a musical instrument, talking on the phone or video-conferencing with friends and family, and multiplayer board and electronic games can provide positive socio-emotional experiences.[53]

Cognitive experiences - Sedentary behaviours could have an impact on cognitive development and academic achievement by exposure to poor or beneficial cognitive experiences, by displacement of more productive sedentary behaviours, and also displacement of MVPA. Some sedentary behaviours encourage passive, rather than active cognitive engagement. Active engagement has shown to have beneficial effects on cognitive development compared to passive activities.[54] Increased technology use with specific content (e.g. content that is hyper-stimulating and fast-paced) may have negative effects on children's attention and cognitive performance.[55] Productive experiences such as school homework may be displaced by other sedentary behaviour with limited useful cognitive impact.[29,30] Additionally, sedentary behaviours displace MVPA which has been shown to have a positive influence on cognitive performance and academic achievement.[56] More positively, sedentary behaviours such as appropriate reading, writing, paper and electronic games may have the ability to improve cognitive development and academic achievement.[57]

Other mechanisms - Sedentary behaviours could have an impact on other aspects of health via a number of mechanisms. Prolonged close vision, for example reading from a book or tablet, could result in increased short-sightedness.[58] Sleep quantity and quality could be impacted by bedroom screen time and blue light from some electronic screens altering chrono-hormone levels.[58]

Research supports a link between sedentary behaviour and poor health outcomes in adults. One of the pathways that sedentary behaviour may influence health is by tracking of the behaviour into adulthood. Total sedentary behaviour may track better from childhood to adolescence than physical activity.[59,60] Total screen time behaviours track moderately from childhood to adolescence.[61] TV was more stable than video games from age 5 to 13,[62] and levels of TV in childhood track into TV in adulthood.[63]

In summary, there are multiple potential mechanisms for various aspects of sedentary behaviours to impact on multiple health and development outcomes. Whilst some mechanisms are specific to certain types of sedentary behaviours, many may result from a variety of sedentary behaviours. The actual mechanisms are complex and the interactions and cumulative effects are not fully understood. However given the considerable exposure of children to sedentary behaviours it is critical that these relationships are better understood.

Question 3: What are the effects of different types of sedentary behaviours on child health and development?

Sedentary behaviour in children has the potential to influence health and development through different types of sedentary behaviour and different mechanisms as seen in Figure 1. This section provides a brief synthesis of the available evidence for different sedentary behaviours to have effects on multiple components of child health and development including cardiometabolic, neuromusculoskeletal, psychosocial, and relevant other outcomes. The focus of this brief review is on children, though where the evidence for children is limited,[64] evidence in adults has been included .[7] Given the differences in types of sedentary behaviour, this brief synthesis is arranged by types of sedentary behaviour and includes: screen time, TV, other screens (excluding TV), non-screen sedentary behaviour, and any sedentary time.

Screen time sedentary behaviours

The Australian Physical Activity Report Card grades were assigned based on compliance with screen time guidelines, as screen time has been given particular attention for having unique effects on children's health.[49] Common limitations to the evidence, however, include cross-sectional designs and that many of the observed associations have a high risk of residual confounding due to sedentary behaviours being related to other lifestyle and socio-economic factors.

Cardiometabolic- The two most commonly studied cardiometabolic outcomes have been obesity and cardiorespiratory fitness. A longitudinal study of Danes found that increased TV and total screen time from adolescence to adulthood was associated with increased body mass index (BMI).[65] A cross-sectional study of 9 to 16 year olds found that BMI was more strongly inversely associated with general screen time than physical activity.[66] Cross-sectional studies have also shown a negative relationship between screen time and cardiorespiratory fitness that is independent of physical activity.[67,68]

Neuro-musculoskeletal- The majority of studies examining musculoskeletal effects of screen time have examined specific types of screens and will thus be discussed in following sections. However, in one cross-sectional study, overall screen time was not associated with bone structure in 9 to 20 year old children when adjusted for physical activity and other factors.[42]

Psychosocial- Compared to other types of sedentary behaviour, screen time has a unique potential to influence psychosocial outcomes due to the content viewed. While the assumption is that screen time negatively affects psychosocial outcomes, few studies have empirically evaluated this relationship. Two cross-sectional studies found increased screen time to be detrimentally associated with depression scores and psychological difficulty, independent of physical activity.[69,70] Additionally, evidence supports the transmission of aggressive behaviours from violent media including TV, movies, video games and internet.[71] Specific uses of technology such as for educational purposes, can, nevertheless, improve psychosocial outcomes and these are discussed in later sections.

Other- Unique characteristics of screen time behaviour have also led to the investigation of other outcomes from screen time including sleep and vision. Among adults, screen time, not total sedentary time, was associated with sleep problems.[72] A review found that increased screen time among children adversely affected sleep, but the effects largely depended on type of screen exposure, age, gender, and day of the week.[73] Screen time may also adversely affect vision. Among university students, sustained periods of close screen work and lack of a screen filter was associated with a greater report of vision problems including dry and tired eyes as well as headache.[74]

Television Watching

While many of the Physical Activity Report Cards assessed children's exposure to sedentary behaviours based on meeting guidelines for total screen time, it is acknowledged that different types of screen devices, used for different purposes, may have differential effects on child health and development. The majority of the evidence supports a detrimental effect of TV on multiple child outcomes.

Cardiometabolic- Several cross-sectional studies support an inverse relationship between TV and cardiometabolic risk in children independent of physical activity.[75-78] These studies have varied in age group and how they have accounted for physical activity.

Additional cross-sectional studies have examined the relationship between TV and BMI, but few studies have tested causal relationships. In a worldwide study of children aged 5 to 15 years there was a positive association between TV and BMI, but the relationship was not adjusted for physical activity.[79] In a longitudinal study in the Netherlands, an increase in TV from adolescence to adulthood was associated with increased BMI in adulthood.[65]

There is a lack of evidence to support a relationship between TV and cardiorespiratory fitness in children. A longitudinal study found that increased TV was associated with decreased cardiorespiratory fitness over 2 years from age 7, but this was not adjusted for physical activity.[80] In female adults, TV was negatively associated with cardiorespiratory fitness, but this was mostly mediated by PA and percent body fat.[81]

Independent of total sedentary and screen time, TV may have additional harmful effects on energy balance due to its relationship with energy intake. Several cross-sectional studies have found an association between increased TV and a poorer diet.[82-84] An experimental study found that energy intake increased while watching TV among 9 to 13 year olds.[34] Advertising during TV may also lead to subsequent increased energy intake as shown in experimental studies.[35,36]

Neuro-musculoskeletal- The evidence for the effects of TV on neuro-musculoskeletal outcomes in children is inconclusive. While one study has found that TV and back pain were positively related,[85] two others have found that TV was not related to back pain[86] or neck and back pain.[87]

Psychosocial- A large number of studies have examined relationships between TV and various psychosocial effects, however many of them have been cross-sectional and unable to discern causality. The majority have found negative associations between increased TV and psychosocial outcomes. Research suggests that children who watch more TV are more likely to have behavioural difficulties, but a variety of measures and definitions of behaviour have been used.[70,88,89] In a longitudinal study of preschoolers aged 2 to 3years, TV was positively associated with externalising problems.[90] Other psychological outcomes have been found to have cross-sectional associations with TV, without adjustment for physical activity, including psychological distress,[91] self-esteem,[92] criminal conviction, antisocial personality disorder, and aggressive traits.[93] While an association between TV and aggressive behaviour has been suggested, the evidence is unclear.[94] Cross-sectional associations suggest that children who watch more TV have poorer cognitive performance including executive function,[95] communication and language development [96] and hyperactivity/inattention.[97]

Other- Both vision and sleep seem to be negatively affected by increased TV. Television (and computer use) was associated with poorer vision in children aged 6 to 18years.[98] Increased TV has been associated with poorer sleep in two longitudinal studies including shorter sleep time unadjusted for physical activity in a longitudinal study of children from 6 months to 7 years[99] and from ages 2 to 4 and 6 to 9 when adjusted for parent-reported PA.[100]

Other screens (not TV)

There have been few studies to isolate other screens (not including TV), with most of them examining computer use or electronic video games.

Cardiometabolic- Saunders et al. found that leisure time computer/video game play in boys (TV in girls) was associated with poorer cardiometabolic profiles among 8 to 11 year olds when adjusted for accelerometer determined physical activity.[77] Another cross-sectional study reported computer game use was positively associated with overweight status in 6 to 14 year old children but not in highly active children.[101]

Neuromusculoskeletal- The associations between technology and low back and neck/shoulder pain have been inconsistent. Cross-sectional surveys of adolescents have found computer and laptop use, greater than two hours, were associated with low back and neck/shoulder pain.[87,102] However, another cross-sectional study of adolescents found that neck/shoulder pain was not related to computer use when adjusted for physical activity.[103] Among children, neck pain was related to increased computer use[58] and repetitive electronic game use has been shown to be related to tendonitis. [45] However, cross-sectional evidence suggests that young children who play greater amounts of interactive video games have improved object control motor skills.[104]

Psychosocial- Numerous studies have examined the relationship between other screens, particularly computers and video games, with both positive and negative psychosocial outcomes. The majority have been cross-sectional which again limits the ability to support causal relationships. A meta-analysis found that violent video game play was related to increased aggressive behaviour, aggressive cognition, and aggressive affect and decreased empathy and prosocial behaviour.[105] Time playing video games has been cross-sectionally related to negative outcomes such as depression, lower academic achievement, conduct problems[106] and poorer working memory,[107] whereas high amounts of computer use have been associated with weaker performance in tests measuring flexibility of attention.[107]

While many of the studies have found detrimental associations, there is also evidence for benefits of other types of screen use. A cross-sectional study of adolescents found that self-reported video usage was positively correlated with improvements in brain structures that correlate with improved executive function.[108] In educational research, technology use (laptops and tablets) has been shown to improve educational outcomes, but often the study designs were weak with small samples and no comparison groups.[109] Technology may be especially beneficial for those with learning disabilities.[110,111]Despite concerns over children becoming technology dependent and losing social interaction skills, adolescents who had more smartphone use also had more face-to-face interactions.[112]

Other - Computer use has been cross-sectionally associated with poorer vision in 6 to 18 year old children.[98]Other media use, compared to TV, was more strongly correlated to health and wellbeing among 8 to 13 year olds, though this was not adjusted for physical activity.[113]

Non-screen sedentary behaviours

Non-screen sedentary behaviours have also been related to various health and development outcomes, but the heterogeneity of behaviours and outcomes precludes a comprehensive review in this paper. Further, much of the research has not separated non-screen sedentary behavior from other sedentary behaviours. A few examples are, nevertheless, provided to illustrate how non-screen sedentary behaviours may influence health. Puzzle play in early childhood has been associated with improved spatial abilities.[114] Unsurprisingly, increased time spent reading during school was related to higher reading achievement, although time spent reading at home was not.[115] Sedentary practices such as meditation are associated with improved cognitive process[116] and self-esteem in school children.[117]

Total sedentary time

Cardiometabolic- Total sedentary time, in activities with a low energy expenditure, has been associated with several cardiometabolic outcomes in a recent review,[6] although, after adjusting for MVPA, the evidence was inconsistent.[16] The strength of association depends on the specific variables examined. For example, in a cross-sectional study of multiple cardiometabolic outcomes among 5 to 10 year-old children, only HDL cholesterol was negatively associated with sedentary time measured by accelerometry, independent of physical activity.[17]

Body mass index has been the most common cardiometabolic outcome measured, yet even the evidence for this relationship has been inconsistent. In adults, a positive relationship between sedentary time and BMI has been found, independent of physical activity.[118] However, a recent review of longitudinal studies among children has concluded that the evidence to support a relationship between sedentary behaviour and adiposity is inconclusive.[119] Reasons for the inconclusive findings may be the predominance of cross-sectional studies, varying measures of sedentary time and inconsistent adjustment for physical activity.[31] One problem with measuring sedentary time with accelerometers may be the misclassification of standing time as sedentary.[120]

Similar to BMI and adiposity, the relationship between sedentary time and cardiorespiratory fitness has been inconsistent. In adults, a large cross-sectional study using NHANES data, found an inverse association between total sedentary time and cardiorespiratory fitness, even when adjusted for exercise. [13] Comparatively in children, a cross-sectional study of over 2,000 10 to 18 year olds did not find an independent relationship between cardiorespiratory fitness and total sedentary time when also adjusted for physical activity.[18] Additional evidence suggests that the relationship may differ between genders.[121]

Of particular interest to cardiometabolic outcomes may be sedentary time accumulated in long, uninterrupted bouts. Literature in adults suggests that these long, uninterrupted bouts may be particularly detrimental,[14,122] though the evidence in children has been less conclusive and predominantly cross-sectional, [17,77,123]In one randomised crossover study, breaking up long bouts of sedentary behaviour in 10 to 14 year olds did not result in changes to cardiometabolic markers.[39]

Neuromusculoskeletal- Few studies have examined the relationship between total sedentary time and neuromusculuoskeletal outcomes including motor skills, bone structure, and musculoskeletal discomfort or pain. One cross-sectional study found that increased sedentary time was negatively associated with motor proficiency among 9 to 10 year-olds, independent of physical activity.[124] Another cross-sectional study examined bone structure and found no association with total sedentary time when adjusted for physical activity.[42] Finally, there has been inconsistent evidence for sedentary time to be related to musculoskeletal pain in children.[125-127]

Psychosocial-Of the multiple psychosocial outcomes that may be potentially affected by sedentary time, very few studies have studied relationships with sedentary time. Two cross-sectional studies have found no associations with self-esteem,[128]and negative associations with sustained attention but no other tests in a cognitive battery.[107]

Other- Total sedentary time may also be associated with other health related outcomes. In adults, there is an increased risk of all-cause mortality with daily sitting time greater than eight hours per day independent of physical activity.[129]

In summary, there is considerable evidence showing sedentary behaviours have implications for child health and development. However the strength of current evidence varies by types of sedentary behaviour and health outcomes as well as the methodological approaches used to examine these relationships.

Further research needed to inform strategies to improve the grade

To better understand which sedentary behaviours are occurring and answer Question 1, national surveillance systems are required to provide robust estimates of children's sedentary behaviour exposure. Data are required from infancy, across childhood to adulthood and need to examine the different types of sedentary behaviours, the different devices used while sedentary, the content or tasks performed and the context of behaviour. Data should also be tracked longitudinally.

To better understand the mechanisms for these impacts and answer Question 2, mechanistic studies are required to test causal pathways and inform critical components for interventions. To better understand the impact of these behaviours and answer Question 3, longitudinal and experimental design studies are required to provide stronger causal evidence of the impacts of the various sedentary behaviours on the full range of important child health and developmental outcomes. Analyses need to consider dose-response relationships while also evaluating mediating and moderating influences such as physical activity, built environment, family socio-economic status and parenting style. More sophisticated statistical approaches are needed, for example compositional analysis may be useful when considering the limited 24-hour nature of each day which can be divided into exhaustive and mutually exclusive components.[130] A life-course approach can be used to evaluate critical windows and pathways of causality.

Further research is needed to improve the measurement of both the amount and nature of children's sedentary behaviours and which strategies are effective to improve sedentary behaviours. Sedentary behaviour measurement needs to be improved to encompass a whole-of-day approach, including sleep and wake time and the full spectrum of wake time 'activity'. Measurement needs to capture not just the total amount of exposure, but also the pattern of exposure and the potential overlap of behaviours with multi-tasking. Methods to accurately capture the context and content/task/device details of behaviours also need to be developed. Standardised and practical methods for classifying and quantifying sedentary behaviours need to be developed to enable valid comparisons between countries. These methods need to match understandings of mechanisms and thus key aspects of behaviour to capture. For example, using inclinometers to measure total sedentary time or validated technology monitoring apps to measure content, accumulation and pattern of screen time. Reevaluation and refinement of partitioning of 'activity' into different intensity-based categories also needs to be conducted, to understand the postural or energy expenditure aspects which relate to outcomes. Comparisons should also be undertaken of countries with healthier sedentary exposure for their children to determine whether some aspects of that society can be promoted in countries with poorer sedentary behavior grades.

Finally, while not reviewed in this paper, continued intervention research is needed to evaluate the efficacy (do the interventions produce a desired effect) and cost efficiency (are the interventions economical) of various strategies to improve sedentary behaviour exposure in children.[131] Reviews of studies evaluating various strategies would provide useful guidance on policies and interventions to be promoted. The importance of tailoring interventions to specific groups of children (age group, gender, socio-economic status, leisure interests etc.) and targeting specific behaviour change (video games, book reading, passive transport etc.) also needs to be evaluated.

Conclusion

The available evidence, whilst incomplete,[64] is sufficiently convincing that sedentary behaviours are critical to child health and development. Nations therefore need to have strategies to promote appropriate exposure to these common behaviours. It appears likely that both the total exposure and pattern of exposure are important for cardiometabolic and neuro-musculoskeletal outcomes and so there is a need to reduce overall sedentary time and prolonged bouts of sedentary time for many children. Aspects of sedentary tasks, such as content, device and context, also appear important to a range of outcomes including psychosocial outcomes and thus need to be addressed.

Failure to adequately address this issue is likely to result in nations facing unsustainable health and economic burdens for poor child and adult health and developmental outcomes. A range of intervention options are available in all nations, targeting the child directly or indirectly via parents, teachers/schools, peers, technology and societal infrastructure. Nations can therefore look forward to improving their grade based on the sedentary behaviour of their children, if they invest sufficiently in understanding this key behaviour and in strategies to promote appropriate behaviour.

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LS, DC, MD, LE, SG, JZ, TO, NS, GT were members of the Research Working Group for the Australian Physical Activity Report Card and reviewed the available evidence. GT and TO were lead investigators and NS was the research project manager. LS and EH drafted the manuscript and all authors reviewed a number of drafts prior to approving the final version.

Table 1: Summary of Sedentary Behaviour Grades in National Physical Activity Report Cards

	Grade	Percentage (%) meeting screen time guidelines (≤2 hours/day unless otherwise noted)*
Ghana	B	79% of 13-17 year olds (global PA guidelines, <3 hours sitting)
Kenya	B	Average of 1.75 hours screen time on school day, 4.25 hours on weekend days for 9-11 year olds
New Zealand	C	60% of 5-9 year olds, 33% of 10-14 year olds
Ireland	C-	54% of 11-15 year olds (TV only)
Colombia	D	42% of 5-12 year olds
Finland	D	22% of 11-15 year olds (on weekdays)
Mexico	D	33% of 10-18 year olds
United States	D	59% of 6-8 year olds, 48% of 9-11 year olds (but ethnic disparities)
Australia	**D-**	**29% of 5-17 year olds**
Canada	F	69% of 5-11 year olds, 19% of 10-16 year olds
Nigeria	F	5-35% of 6-18 year olds (<3 hours per day)
Scotland	F	24% of 11-15 year olds (TV only)
South Africa	F	Average 3 hours TV per day for 10-17 year olds

*Note: estimates are taken from respective country report cards, and the definitions of meeting guidelines varied, as did the survey instruments used and age groups assessed

Figure 1. Sedentary behaviours, mechanisms and impact on child health and development

Figure 2. Average proportion of daily wake time spent in ‘activity’ of different intensity for Australian children aged 10-12 years (data from [19])

Figure 3. Daily time Australian children spend being sedentary (data from the Australian National Children's Nutrition and Physical Activity Survey [25])

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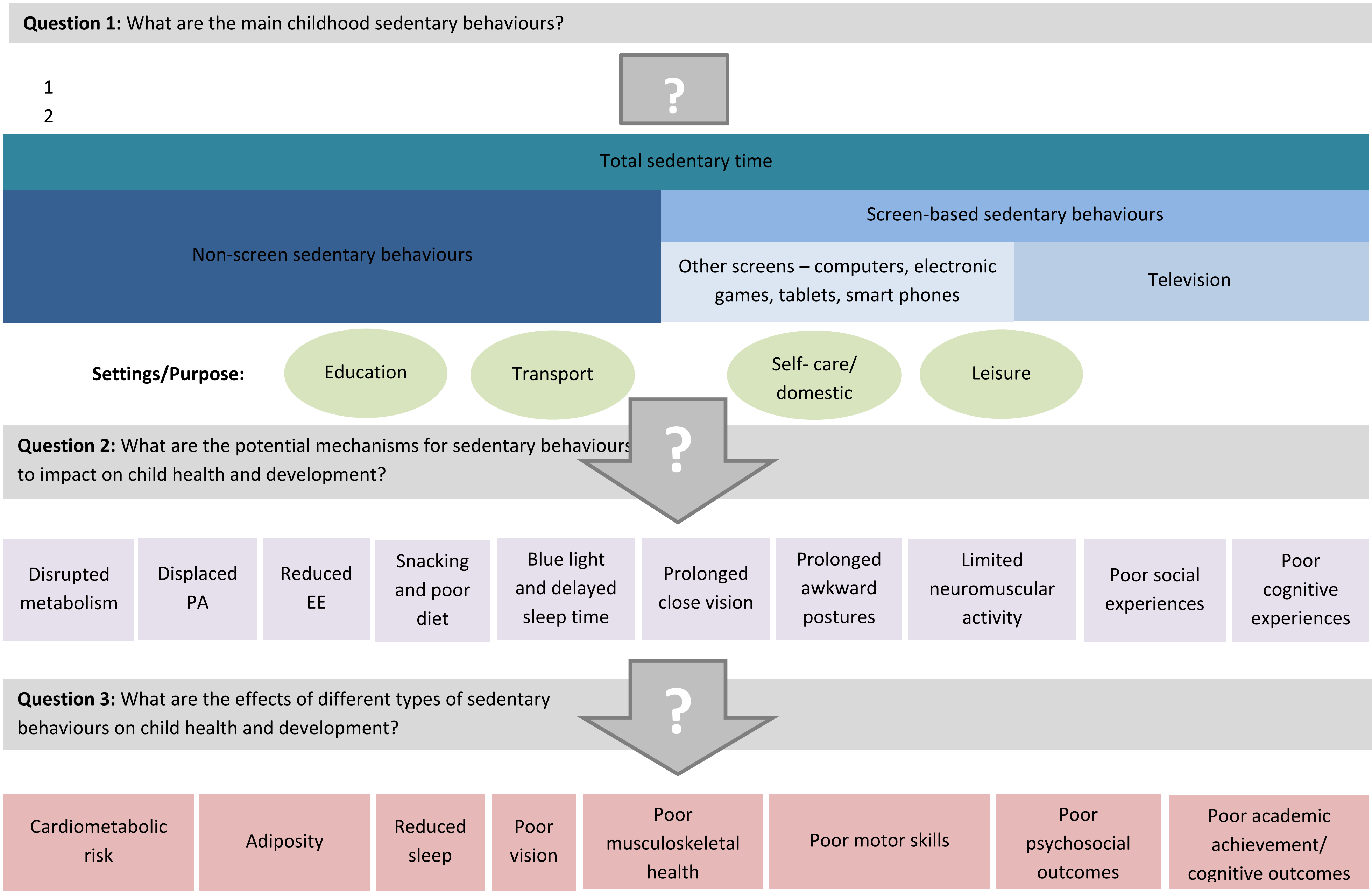

Question 1: What are the main childhood sedentary behaviours?
?
Total sedentary time
Non-screen sedentary behaviours
Screen-based sedentary behaviours
Other screens – computers, electronic games, tablets, smart phones
Television
Settings/Purpose:
Education
Transport
Self- care/ domestic
Leisure
Question 2: What are the potential mechanisms for sedentary behaviours to impact on child health and development?
?
Disrupted metabolism
Displaced PA
Reduced EE
Snacking and poor diet
Blue light and delayed sleep time
Prolonged close vision
Prolonged awkward postures
Limited neuromuscular activity
Poor social experiences
Poor cognitive experiences
Question 3: What are the effects of different types of sedentary behaviours on child health and development?
?
Cardiometabolic risk
Adiposity
Reduced sleep
Poor vision
Poor musculoskeletal health
Poor motor skills
Poor psychosocial outcomes
Poor academic achievement/ cognitive outcomes

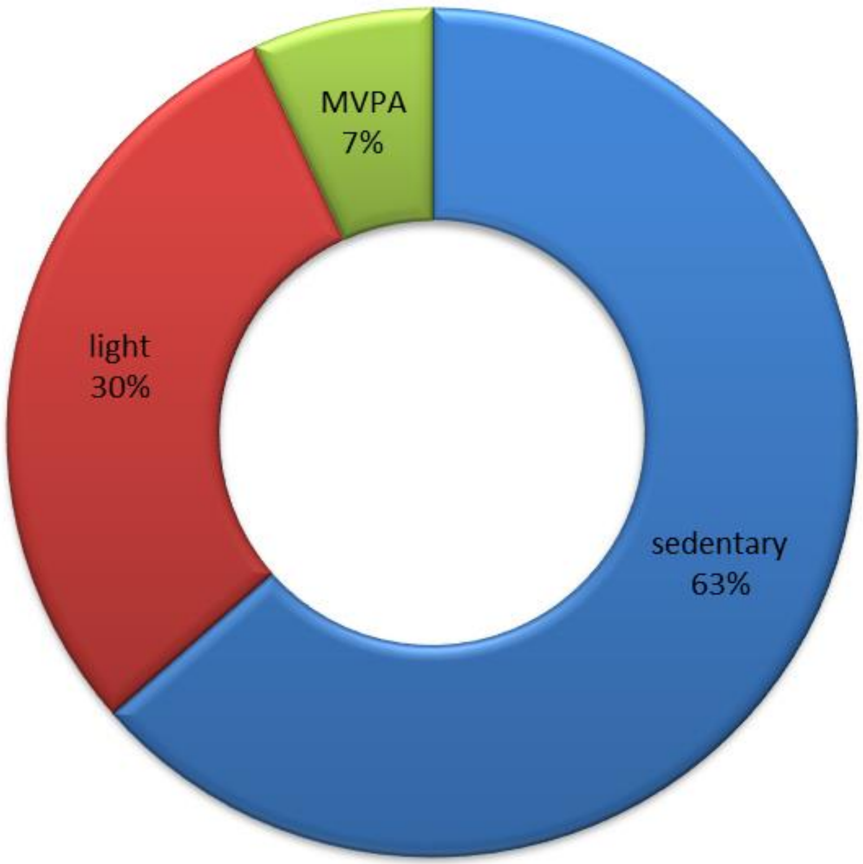
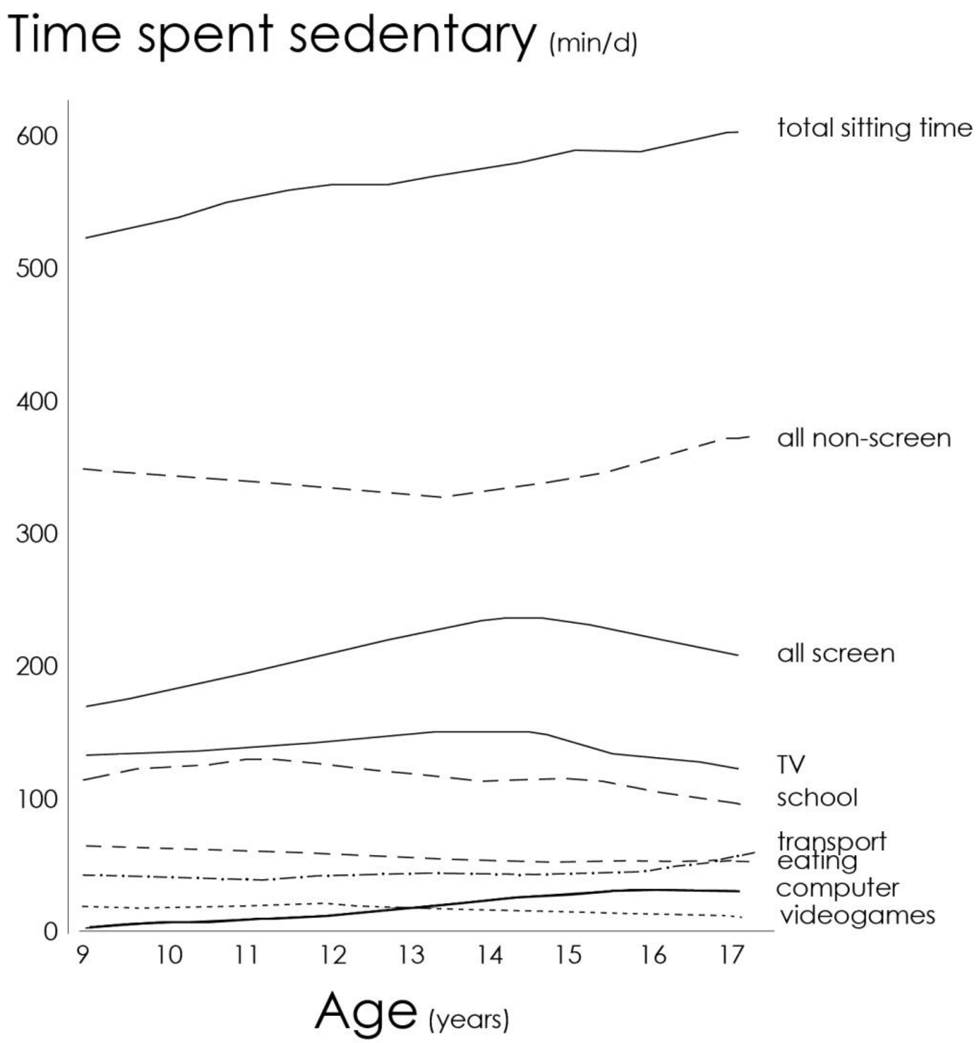


Figure 2


Time spent sedentary (min/d)
600
500
400
300
200
100
0
total sitting time
all non-screen
all screen
TV
school
transport
eating
computer
videogames
9
10
11
12
13
14
15
16
17
Age (years)

1

2 Figure 3