Chapter 7

General discussion
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This thesis aimed to extend the knowledge on sedentary behaviour among young people by: (1) summarizing the evidence on the prospective relationship between young people’s sedentary behaviour and indicators for biomedical health; (2) describing differences in body movement across various sedentary activities, measured by accelerometer counts, muscle activity and heart rate; (3) examining tracking of total sedentary time, prolonged sedentary time and their day-to-day variation during childhood; (4) examining child- and parent-related correlates of total and prolonged sedentary time in 5- to 6-year-old children; (5) exploring child- and parent-perceived determinants of children’s sedentary behaviour, using concept mapping with 11- to 13-year-old children and their parents. This general discussion will elaborate on the main findings of research described in earlier chapters. First, the main findings are summarized. Second, the methodological considerations are discussed. Next, the findings are interpreted and implications and directions for future research are provided. This chapter ends with an overall conclusion.

Summary of main findings

Chapter 2 summarizes the evidence on the prospective relationship between young people’s sedentary behaviour and indicators for biomedical health, overall and stratified by type of sedentary behaviour (TV viewing, computer use/games, screen time and objectively assessed sedentary time). We concluded that the evidence for a prospective relationship between young people’s sedentary behaviour and biomedical health indicators is unconvincing, and varies by type of sedentary behaviour and biomedical health indicator. We found moderate-to-strong evidence for a relationship of overall sedentary time with two anthropometric indicators (overweight/obesity and weight-for-height), one cardiometabolic biomarker (HDL-cholesterol) and some fitness indicators (fitness, being unfit), however, this evidence is mainly based on studies measuring TV viewing time. For other health indicators the evidence was inconsistent or lacking. When stratifying the evidence by the type of sedentary behaviour, we found moderate-to-strong evidence for a relation of TV viewing with increased risk for overweight/obesity, increased incidence of overweight/obesity and decreased fitness. For screen time we found moderate-to-strong evidence for a relation with increased BMI and increased risk for overweight/obesity. For computer use/games and objectively assessed sedentary time we found insufficient evidence or no evidence for a relationship with biomedical health indicators. The meta-analysis indicated that baseline TV viewing or computer use was not significantly related with BMI at follow-up.

Chapter 3 describes body movement differences across various sedentary activities in children and adolescents, assessed by acceleration of the hip-, thigh- and wrist, muscle activity and heart rate. Body
movement differences between sedentary activities and standing were also described. Children showed significantly more body movement during sedentary activities and standing than adolescents. In both age groups, screen-based sedentary activities involved less body movement than non-screen-based sedentary activities. The magnitude of differences depended on the device and its position. For example, body movement differences between screen-based and non-screen-based sedentary activities were most pronounced for heart rate and acceleration of the thigh. Hip-worn accelerometers were unable to detect differences in body movement between various sedentary activities. Differences in body movement during standing and sedentary activities were relatively small.

Chapter 4 describes tracking of young people's total and prolonged sedentary time as well as their day-to-day variation using the International Children's Accelerometry Database (ICAD). Moderating effects of gender and age on tracking coefficients were also examined. Longitudinal accelerometer data was analyzed of 5,991 children from eight studies in five countries. Average total sedentary time at study level ranged from 246-387 minutes per day at baseline and increased annually by 21 minutes per day. This increase consisted almost entirely of prolonged sedentary time, defined as sedentary time accumulated in bouts of at least 10 minutes. Total and prolonged sedentary time tracked moderately. Tracking of day-to-day variation in total and prolonged sedentary time was low. Tracking of total sedentary time was higher during childhood than during the transition from childhood to adolescence. Tracking of total and prolonged sedentary time was slightly higher for boys than for girls, while tracking of day-to-day variation was similar for boys and girls.

Chapter 5 describes child- and parent-related correlates of total and prolonged sedentary time in 5- to 6-year-old children. Additionally, child- and parent-related correlates of total and prolonged sedentary time during weekend days and the after school period were described. Few potential correlates were associated with young children's total or prolonged sedentary time and most associations differed by time period: overall, after school, and weekend days. Higher child MVPA was the only correlate that was consistently associated with lower total and prolonged sedentary time across all time periods. Higher total sedentary time in parents was associated with higher overall total sedentary time and weekend total sedentary time in their children. Higher body mass index z-scores of children were associated with lower overall total and prolonged sedentary time. Girls engaged in less prolonged sedentary time after school than boys. Older children engaged in less total sedentary time during the weekend.

Chapter 6 describes child- and parent-perceived determinants of children's sedentary behaviour, using concept mapping with 11- to 13-year-old children and parents. Children and parents identified six
similar potential determinants, and both rated these as important: “sitting because it is the norm (I have to)” and “sitting because I can work/play better that way”. In addition, children rated “there is nobody to play with” as an important potential determinant for engaging in sedentary behavior. Parents rated “my child is tired, wants to relax, wants to rest”, as an additional important potential determinant. Future observational and intervention studies are needed to examine if these child- and parent-perceived determinants are indeed related with children’s sedentary time.

**Methodological concerns**

Some methodological limitations have to be considered when interpreting the findings of the research described in this thesis. Important methodological aspects include: generalizability of findings, measurement methods and research design.

**Generalizability of findings**

The heterogeneity across the studies included in the systematic review was large (chapter 2). There were for example large differences in measurement of sedentary behaviour and health indicators, statistical analyses and reported types of effect size. This limited the statistical pooling in the meta-analyses and consequently the studies included in our meta-analyses may not be representative of all performed studies. Also, the studies included in our systematic review are not globally representative as all studies were conducted in North America and Europe. Tracking of sedentary time was examined using the ICAD (chapter 4). Although, a main strength of the ICAD is that it is a large harmonised international dataset, the data is not globally representative. Moreover, data from individual studies included in the ICAD may not be nationally representative due to sampling strategies, non-response, loss to follow-up and baseline samples with valid accelerometer data being different from total study samples. Limitations in generalizability due to limited representativeness of study samples were also observed in the B-Proact1v study (chapter 5) and the concept mapping study (chapter 6). Data from the B-Proact1v study was used to examine child- and family-related correlates of total and prolonged sedentary time. In the B-Proact1v study, children and one of their parents living within the greater Bristol area wore an accelerometer and parents also completed a questionnaire. Although the sample was relatively large (n = 863 children), there was little ethnic diversity and participants were slightly less deprived than the average UK population. Our sample may therefore not be representative for the UK and caution should be taken when generalizing our findings. The concept mapping study (chapter 6) was performed with 11- to 13-year-old children and parents to explore potential determinants of children’s sedentary time. Despite that a relatively low number of children participated (n = 38), included children had diverse backgrounds (i.e. low and medium SES, from
schools located in urban and rural areas). Similar clusters were identified across schools and at the last school no new topics emerged in the underlying statements, indicating saturation. The participating parents, who were not necessarily the parents of the participating children, were mainly highly educated, which may have limited the representativeness of parent-identified determinants. Because older or younger children may perceive other potential determinants of their sedentary time, results may not be generalizable to children of other ages. In chapter 3, body movement differences were examined across commonly performed sedentary activities. The sedentary activities ‘watching movies’, ‘computer gaming’, ‘tablet use’ and ‘media multitasking’ were grouped into ‘screen-based activities’ because body movement during these activities was very comparable. The activities ‘drawing’ and ‘just sitting’ were grouped into ‘non-screen-based sedentary activities’. Because only a limited number of commonly performed sedentary activities was included in this study, the result of our study may not be generalizable to all screen-based and non-screen-based sedentary activities.

Accelerometer measurements
In this thesis a large part of the findings for sedentary time are based on measurement with Actigraph accelerometers (chapters 3, 4 and 5). Also, 11 of the 109 studies included in the systematic review (chapter 2) used accelerometers to assess sedentary time. Accelerometers are small, lightweight measurement devices and are most commonly attached to the hip using an elastic belt. Accelerometers measure acceleration in three planes of motion; the X-axis (medio-lateral axis), Y-axis (vertical axis) and Z-axis (antero-posterior axis) and are most commonly attached to the hip. Currently, only information from the Y-axis is used to assess sedentary time and time spent in physical activity. For data processing, raw acceleration data is converted into an counts during a predefined interval (i.e. epoch length). To translate accelerometer counts into estimates of sedentary time and physical activity, subjective data reduction decisions are needed. Currently, there is no consensus about the optimal data reduction criteria, limiting comparability of findings between studies when different data reduction criteria are applied. Moreover, the differences in data reduction criteria may influence associations with health outcomes (1). Subjective decisions in the data reduction process include: the selection of cut-points and an epoch length to classify sedentary behaviour and different intensities of physical activity; the definition of non-wear time; the definition of a valid day; and the number of valid days needed for a representative estimate of sedentary time. First, to assess sedentary time lab-studies and free-living studies in children recommend to use a cut-point of 100 counts/minute (CPM) for acceleration in the Y-axis (2-4). While this cut-point is most commonly used, other cut-points are used as well. For example, in the systematic review (chapter 2) two studies used a cut-point as high as 1100 CPM, which is likely to overestimate sedentary time. An epoch length for data aggregation of 15-seconds is also commonly used and recommended to estimate MVPA, because a shorter epoch length
may better capture children’s sporadic activity pattern (5). When using a 15-seconds epoch length for data-analysis, conversion of the 100 CPM cut-point to 25 counts/15 seconds is required. However, the 100 CPM cut-point and 25 counts/15 seconds cut-point may result in different estimates for sedentary time. In general, less sedentary and more light intensity physical activity is found with increasing epoch length (6-10). Additional analyses of the controlled laboratory study on body movement differences (chapter 3) showed that more sedentary time is misclassified as light intensity physical activity when using the 25 counts/15 seconds cut-point (unpublished results). In the study using the ICAD database (chapter 4) and in the B-Proact1v study (chapter 5) we applied an epoch length of 60 seconds in the data-analysis because these studies were focused on sedentary time. The second decision in data reduction is the definition of non-wear time. When a person is not wearing the accelerometer, the accelerometer will not measure any acceleration, resulting in a period of consecutive zero counts in the data. However, when sitting still, accelerometer counts can be zero as well. Therefore, it is very important to differentiate non-wear time from sedentary time when analyzing accelerometer data. The definition of non-wear time impacts sedentary time estimates (11). A definition of 60 or more minutes of consecutive zero counts has been recommended to define non-wear time in youth (11). This definition was applied in chapter 4 and 5. Finally, a valid day (i.e. the minimum number of hours data per day) and the minimum number of valid days need to be defined. In order to obtain a representative estimate for total sedentary time, it is recommended to use accelerometer data of at least six days with minimum of eight valid hours and preferably including one weekend day (11). In chapter 4 and 5, we used a less strict definition for the number of valid days, namely at least four valid days of data (of at least eight hours), including one weekend day. We used a less strict definition because in the B-Proact1v study (chapter 5) we had only five days of data available as children and one of their parents were asked to wear an accelerometer during all waking hours for five consecutive days (including two weekend days). Also, in the ICAD (chapter 4) three out of the eight included studies had only four days of accelerometer data available. Therefore, we used a definition of four valid days, including one weekend day, for all studies within the ICAD. Increasing the number of days would have resulted in a major loss of participants, decreasing sample representativeness.

One main disadvantage of accelerometers is that standing is often misclassified as sedentary behaviour (12) since standing does not result in a substantial acceleration of the hip. The thigh-worn ActivPAL monitor overcomes this problem by classifying posture (i.e. sitting/lying, standing or stepping) instead of acceleration using inclination of the thigh (12). However, a main disadvantage of the ActivPAL is the assessment of MVPA. For estimation of time spent in the different intensities of physical activity (i.e. light, moderate and vigorous) the cadence function (steps/minute) can be used (13). However, this still requires application of cut-points which are less well studied compared to accelerometers (13).
Another disadvantage of accelerometers is that they provide an estimate of sedentary time in general but cannot provide contextual information about the type of sedentary activities (e.g. TV viewing, sedentary gaming). Questionnaires can be used to obtain information on specific sedentary activities, however, a questionnaire with both acceptable validity and reliability in youth is lacking (14). The results of the controlled laboratory study on body movement differences between sedentary activities (chapter 3) suggest that it may be possible to distinguish between categories of sedentary activities using a combination of measurement devices, e.g. screen-based from non-screen-based sedentary activities (combining a thigh-accelerometer and heart rate) and sedentary activities with arm-movement from sedentary activities without arm-movement (combining a thigh- and wrist-accelerometer). Future research is needed to further explore these possibilities.

Taken together, all currently used methods to assess sedentary time suffer from methodological limitations. In order to advance the field of sedentary behaviour research is needed into optimization of measurement and analysis methods.

**Study design**

To accurately measure body movements across various sedentary activities in children and adolescents, we used a controlled laboratory study (chapter 3). Possibly, the lab setting and wearing of the monitors may have influenced the behaviour of our participants during the activities. Besides insights in body movement during sedentary activities, the data also gave insights in measurement and accurate classification of sedentary behaviour. For example, wrist-worn accelerometers differences in accelerometer counts were small between standing and sedentary activities requiring arm-movement, especially for the dominant hand. Differentiating sedentary behaviour from standing is therefore problematic with wrist-mounted as well as hip-mounted accelerometers. This is important knowledge because wrist-worn accelerometers receive increased attention for obtaining estimates of sedentary behaviour and physical activity (15-17) since this position may increase wear compliance (18). The focus of this study was on sedentary activities and because of the participant burden, the study was limited to seven different sedentary activities, a standing activity and a dancing activity as control activity. However, it would have been interesting as well to include a diverse set of activities of light intensity, to examine the degree of body movement differences with the sedentary activities. Also, when assessing sedentary time with accelerometers, activities of light intensity can be misclassified as sedentary behaviour. Therefore, including various activities of light and moderate-to-vigorous intensity in this study would have provide more knowledge about the degree of misclassification of both physical activity as well as sedentary behaviour.
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In chapter 5, child- and parent-related correlates of total and prolonged sedentary time were examined using a cross-sectional study design. Since cross-sectional studies measure exposure and outcome at the same time point, it is not possible to interfere about causality of associations. Longitudinal and intervention studies are needed to gain more insight in factors that are causally related with children’s sedentary time. Our concept mapping study (chapter 6) yielded new insights in potential determinants of sedentary behaviour and their perceived importance. However, observational and intervention studies are needed to confirm that the identified child- and parent-perceived determinants are indeed related with children’s sedentary behaviour.

Are potential health effects of sedentary time likely to be independent of physical activity?

Health consequences may not easily manifest in young people, because young people are cardiometabolically still very healthy and most health effects develop slowly over time (19). This may be one explanation for the lack of convincing evidence for health effects of young people’s sedentary behaviour. In adults, sedentary behaviour has been associated with all-cause mortality, fatal and non-fatal cardiovascular disease, type 2 diabetes, metabolic syndrome and incidence of ovarian, colon and endometrial cancers (20). The health effects of sedentary behaviour has received a lot of media attention over the last years. Headlines like ‘sitting is the new smoking’ and ‘health effects of sitting cannot be counteracted by physical activity’ have resulted in a public impression that there is convincing scientific evidence for detrimental health effects of sedentary time. However, the current evidence for health effects of sedentary behaviour has been questioned as it is uncertain if health effects of sedentary behaviour are truly independent of physical activity (21). Even if studies adjusted for MVPA as a confounder, the question remains if this is sufficient to conclude on independent effects as adjusting ignores the possibility of effect modification (i.e. the relationship between sedentary behaviour and health is dependent on the level of MVPA) (21). A meta-analyses of Ekelund et al. (22) demonstrated that the association of sedentary time with all-cause mortality was dependent on adults’ level of physical activity. Sitting for more than 8 hours/day was associated with increased mortality risk among inactive adults. Engaging in MVPA for 25-35 minutes/day lowered the risk. The increased mortality risk was eliminated in adults with high levels of MVPA (60-75 minutes/day) (22). Therefore, it remains uncertain to what extent the health effects of sedentary time are caused by effects of too little physical activity. Another basis on which the independent health effects of sedentary time are questioned is the absence of a convincing biological mechanism explaining health effects of sedentary time irrespective of physical activity (21). The first proposed mechanism is based on an animal study and suggest that a loss of contractile stimulation of weight bearing muscles result in a decrease of lipoprotein lipase activity in muscle capillaries. Lipoprotein lipase is a central enzyme
in lipid metabolism and is involved in triglyceride uptake from the blood and regulation of cholesterol levels (23, 24). A decrease in muscle lipoprotein lipase activity is therefore hypothesized to result in increased blood triglyceride levels during prolonged sitting, which will increase cardiometabolic risk if sustained over time. To date, this mechanism has not been confirmed in humans and therefore its plausibility is questioned (21). A second proposed mechanism suggest that prolonged sitting may reduce glucose metabolism as activity breaks during sedentary behaviour have been shown to stimulate metabolic pathways related to glucose uptake and insulin sensitivity (25, 26), thereby potentially lowering postprandial blood glucose levels compared to prolonged sitting. A last proposed mechanism suggests that reduced leg blood flow during prolonged sitting causes endothelial cell dysfunction, which subsequently increase the risk for developing peripheral artery disease (27). However, those three proposed mechanisms do not provide a convincing explanation for independent health effects of prolonged sitting since they can also be caused by a lack of physical activity and can be counteracted by engaging in physical activity.

**Should we target children’s sedentary behaviour in order to improve their cardiometabolic health?**

The health effects of sedentary behaviour are not well understood and to date, there is unconvincing evidence for health effects of children’s sedentary behaviour. In the review described in chapter 2 we found moderate-to-strong evidence for a relationship between TV viewing with increased risk for overweight/obesity, increased incidence of overweight/obesity and decreased fitness. The questions is whether these relationships are indeed caused by sitting per se. TV viewing time is associated with unhealthy eating habits as well (14), which may explain the observed associations with overweight. Studies examining health effects of TV viewing do not always adequately account for diet as well as for MVPA.

Despite the lack of convincing evidence for health effects of sedentary behaviour, Dutch physical activity guidelines advice children ‘to avoid long periods sitting down’ (28). While not scientifically underpinned, limiting sedentary time is unlikely to be harmful and may potentially increase MVPA (19). However, since evidence for health effects of MVPA are well established (29, 30) and the evidence for health effects of children’s sedentary behaviour is not convincing at this moment, the focus should be on increasing children’s MVPA.

**Future research**

In order to better understand the potential health effects, it is needed to improve the measurement and analysis of sedentary behaviour and to obtain more insight in physiological mechanisms explaining these potential health effects. To date, epidemiological research has focused on health effects of the
total volume of sedentary time, in which relationships with health outcomes are adjusted for the total volume of physical activity. However, this approach ignores the pattern in which sedentary behaviour and MVPA are alternated throughout the day, including the duration and frequency of their bouts. Also light physical activity may be important to consider as it may have beneficial health effects as well (31). Relatively little is known about the potential beneficial health effects of light intensity physical activity, but it is gaining increased research interest. Differences in accumulation patterns of sedentary behaviour, light intensity physical activity and MVPA may be of importance for health. The difficulty lies with the development of a method to study such patterns within epidemiological studies, because a lot of different variables should be summarized into a measure for pattern. However, the first efforts have been made in the development of such a method (32). Ultimately, health effects of 24-hour movement patterns should be examined, including sleep as well. Currently accelerometry data seems to be most suitable method to study such patterns because accelerometers can be used to measure the whole movement spectrum including sleep. As described earlier accelerometry has some important limitations which need to be overcome, including a lack of consensus on cut-point and data reduction criteria and the inability to separate sitting from standing. Regarding physical activity, accelerometers are for example unable capture cycling, swimming and weight training. A combination of measurement devices may provide a solution for this but possibilities have to be investigated. Also, algorithm to identify sleep should be advanced (5). To obtain more insight into health effects of 24-hour patterns, future research is also needed into biological mechanisms able to explain potential health effects of different patterns.

**Overall conclusion**

This thesis aimed to extend the knowledge on sedentary behaviour among young people. Sedentary time increases during childhood and adolescence which is almost entirely due to increases in prolonged sedentary time. Total and prolonged sedentary time track moderately in young people, meaning that young people with relatively high sedentary time are likely to remain among the people with relatively high sedentary time as they grow older. Factors influencing children’s sedentary behaviour are not well known. In 5- to 6-year-old children higher MVPA was associated with less sedentary time. According to 11- to 13-year-old children and parents important potential determinants of children’s sedentary time are “sitting because it is the norm (I have to)” and “sitting because I can work/play better that way”. Not all sedentary activities are equally ‘sedentary’ as body movement is lower during screen-based sedentary activities than during non-screen-based sedentary activities. Besides, children have more body movement during sedentary activities and standing than adolescents. Evidence for health effects of young people’s sedentary behaviour is unconvincing.
Current evidence is limited by the measurement of sedentary behaviour and it is uncertain if health effects of sedentary behaviour are truly independent of physical activity. In order to better understand potential health effects, future research should shift away from studying total volumes of sedentary time and physical activity, while adjusting for each other, to studying 24-hour patterns of accumulation and alternation of sedentary behaviour, the different intensities of physical activity and sleep.
References


