Conceptualizing, Defining, and Measuring Before-School Physical Activity: A Review With Exploratory Analysis of Adolescent Data

Manuscript title: Conceptualising, defining, and measuring before-school physical activity: a review with exploratory analysis of adolescent data

Submission date: 25 November 2022

Revision 1 submission date: 19 February 2023

ABSTRACT

Physical activity (PA) among children and adolescents is often reported by time segments centred around the school day, including before school. However, there is no consistent approach to defining the before-school segment, to accurately capture PA levels and facilitate synthesis of results across studies. Therefore, this study aimed to: *a*) examine how studies with children and adolescents have defined the before-school segment; and *b*) compare adolescents' before-school PA using various segment definitions. We conducted a systematic search and review of literature from six databases, and subsequently analysed accelerometer data from Australia (*n*=472, mean age 14.9, 40% male), to compare PA across five before-school definitions. Our review found 69 studies reporting before-school PA, 59 of which used device-based measures. Definitions ranged widely, but justifications were rarely reported. Our empirical comparison of definitions resulted in a range of participants meeting wear time criteria (≥3 days at >50% of segment length) from the latest-starting definition (30 minutes prior to school; *n*=443) to the earliest-starting definition (6:00am-school start; *n*=155), implying that for many participants, accelerometer wear was low in the early hours due to sleep or non-compliance. Statistically significant differences in light and moderate-to-vigorous PA (mean minutes/school-day, proportion of segment length, proportion of wear time) were found between definitions, indicating that before-school PA could potentially be underestimated depending on definition choice. We recommend that future studies clearly report and justify segment definition, apply segment-specific wear time criteria, and collect wake time data to enable individualised segment start times and minimise risk of data misclassification.

INTRODUCTION

There are numerous health benefits for children and adolescents who engage in sufficient physical activity (PA) (Cesa et al., 2014; McMahon et al., 2017; Poitras et al., 2016). Accordingly, there is strong emphasis among governments, researchers and health agencies on monitoring and improving PA levels (World Health Organization, 2018). Studies may focus on one or more parts of the day, or discrete segments, when reporting results (Saint-Maurice et al., 2018). Such research can enhance our understanding of variability in PA patterns (e.g., across the school day) and our understanding of PA in specific temporal contexts that may benefit from intervention (Fairclough et al., 2012). For example, one study found highly active primary school children engaged in more moderate-intensity PA before school than low active children, prompting a recommendation to focus PA promotion efforts on segments involving opportunities for 'discretionary PA' (Fairclough et al., 2012).

While the start and end times of some segments, such as school-day and recess, may be easily delineated by school timetables, other periods important for PA, such as before and after school, are subject to ambiguity in how they are defined. This inexact interpretation of segments outside of school hours has led to variability in their expression within PA literature. While some variability is to be expected between contexts (e.g., different school start/end times, challenges may arise if these segments are inconsistently operationalised or inadequately defined. For example, in the before-school segment there is potential to underestimate (e.g., excluding PA accumulated early in the morning, such as sport training) or overestimate PA (e.g., including PA accumulated during school hours if accurate school bell times are not considered), and making meaningful comparisons across studies is likely to be difficult (Fairclough et al., 2012). To overcome similar challenges, a standardised definition of the *after*-school segment has been proposed (i.e., end of school to 6:00pm) (Arundell et al., 2013).

A need for higher quality research focused on the before-school segment has been identified, along with a need for more studies examining PA outcomes (Woodforde et al., 2022). However,

this segment has not been standardised or conceptualised, and inconsistent definitions and time parameters are likely to persist. Conceptually, a complete view of the before-school segment may entail measurement of PA from waking until the time school officially starts, likely represented by the beginning of timetabled classes. Typically, this period includes time spent at home, in transit to school, and on school grounds before classes begin. Additional before-school activities away from home or school may include early morning sport or shopping. Rather than including all waking time before school, researchers may opt to measure only one component, such as PA at school, to represent the before-school segment. Such differences in the conceptualisation and description of before-school PA contribute to challenges in making comparisons and synthesising data across studies.

There is a need to understand decisions made in defining, measuring and reporting before-school PA, and the potential implications of these decisions for before-school PA estimates and opportunities for intervention. Therefore, this study's aims were: *a*) to examine how the before-school segment has been defined in the literature, and how before-school PA has been measured in studies among children and adolescents; and *b*) to conduct exploratory analyses comparing adolescents' PA estimates derived from various before-school segment definitions.

METHODS

To address each aim, this study's methods are twofold. Part A involved a systematic search and review (Grant & Booth, 2009) to synthesise evidence relating to definitions of the before-school segment and measurement of before-school PA. As defined in Grant and Booth's (2009) typology of reviews, the systematic search and review "combines strengths of critical review with a comprehensive search process" and "typically addresses broad questions to produce 'best evidence synthesis'". This review method, which distinguishes itself from systematic review by not requiring quality assessment, is appropriate for synthesising evidence and appraising recommendations for practice (Grant & Booth, 2009). This aligns with the first aim of the study. Part B, informed by the findings of Part A, involved quantitative analysis of adolescents' accelerometer data to consider

potential implications for PA measurement by applying existing definitions of the before-school segment.

Part A

Search strategy

PubMed, Embase, Scopus, SportDiscus, ERIC, and CINAHL were searched in August 2021. The search strategy (Supplemental File 1) was finalised following a scoping search of the literature and consultation with an academic librarian.

Inclusion and exclusion criteria

English-language peer-reviewed articles reporting on original research were eligible for inclusion. Articles were included if they reported primary or secondary school children or adolescents' PA in a distinct before-school segment, derived from either observational or experimental studies. Articles were excluded if they reported (i) sedentary behaviour only, (ii) PA for a segment overlapping with school time, or (iii) combined PA during the before-school segment *and* another segment.

Article selection

Search results were exported to EndNote (The EndNote Team, 2013) for duplicate removal. Unique articles were imported into Covidence (*Covidence systematic review software*) for independent title/abstract and subsequently full-text screening by two reviewers ([redacted]). Disagreements at either screening stage (n=48 at title/abstract, n=9 at full-text) were resolved through discussion.

Data extraction and synthesis

Using an electronic spreadsheet, the following characteristics were extracted by one reviewer and confirmed by another ([redacted]): publication year, country, study design, sample size (schools, participants), participant age, school stage, PA measurement type and tool, reported unit of PA, wear time criteria and before-school wear time (device-based PA measurement studies), and challenges reported relating to measurement of before-school PA. For enhanced rigour, the

following characteristics that are critical to the study's first aim were independently extracted by two reviewers ([redacted]): definition applied to the before-school segment, and justification provided for the definition. Disagreements were resolved through discussion. All characteristics were descriptively synthesised.

Part B

Context and participants

The empirical component of this study used cross-sectional data from the [redacted] study, collected between August 2014 and December 2015. Participants were adolescents from schools selected from each of four stratifications of walkability and income within [redacted], Australia. Principals from 18 schools consented for their school to participate. Additional recruitment details have been reported elsewhere (Parker et al., 2019). Consent was received for 528 participants, of whom 472 provided accelerometer data. Despite not including younger children, the sample of adolescents was suitable for Part B's exploratory purposes to examine the potential for differences in PA estimates when applying different segment definitions.

Device-based physical activity measurement

Participants were asked to wear an ActiGraph model GT3X+ accelerometer on their waist during waking hours for eight consecutive days, removing it for water-based activities. This device is reliable for measuring PA in adolescents (De Vries et al., 2009). Some participants were asked to wear the accelerometer on additional days due to insufficient overall wear (<4 weekdays with 10 hours and no weekend days with 8 hours). Periods with ≥60 minutes of consecutive zero counts were classified as non-wear time (Chinapaw et al., 2014). Light PA (LPA) and moderate-to-vigorous PA (MVPA) were defined using age-specific, validated, cut-points (MVPA: ranging from ≥2220 counts per minute [cpm] to ≥3499cpm, LPA: >100cpm and less than MVPA threshold) (Trost et al., 2002). For participants aged >18 years, Freedson adult cut-points were used (MVPA: ≥1952cpm, LPA: >100cpm and less than MVPA threshold) (Freedson et al., 1998).

Data processing

Using a customised Excel macro, accelerometer files were processed to provide wear time, LPA and MVPA in the before-school segment, defined in five ways: *Definition 1 (D1) 6:00am-school start*, *Definition 2 (D2) 7:00am-school start*, *Definition 3 (D3) 8:00am-school start*, *Definition 4 (D4) 60 minutes prior to school start time*, and *Definition 5 (D5) 30 minutes prior to school start time*. These definitions were chosen to replicate the three most common definitions found in Part A (establishing *D1*, *D4*, and *D5*), and to examine implications of delaying the start time of the most common definition, *D1* (establishing *D2* and *D3*). A segment on a given day was considered valid when wear time exceeded 50% of segment length. Given the lack of guidelines regarding minimum wear time in the before-school segment, we based our decision on exploratory analyses with our data, considering wear time and sample size. Specifically, we found a mean wear time of 53% using the longest segment definition and decided that a wear time criterion of 50% would provide sufficient PA data for each definition, without severely compromising sample size. For each definition, a minimum requirement of 3 weekdays of valid wear during the segment was established, consistent with recommendations for reliable whole-weekday estimates of PA for a school week (Mattocks et al., 2008).

Statistical analysis

Data analyses were conducted using Stata (version 17.0) (StataCorp, 2021). Segment length for each definition, age and sex of participants (self-reported) providing valid accelerometer data under each definition (≥3 days at >50% of segment length), days of valid accelerometer wear, and accelerometer wear time (minutes and proportion of segment length) were examined through descriptive statistics.

For each participant, duration, proportion of segment length (variable between schools in segments *D1*, *D2* and *D3* due to variable school start times), and proportion of segment wear time spent in LPA and in MVPA were calculated and averaged per school-day. PA was descriptively summarised for each definition, with the inclusion of bias-corrected and accelerated bootstrap 95%

confidence intervals around the mean. For each definition, descriptive analyses were conducted to include all participants with valid data for the segment as defined, and repeated to only include participants who had valid data for all five definitions (balanced sample between segment definitions). Group differences between the participants with complete data across segment definitions and those without were examined using *t*-tests for age and daily MVPA, and a chi-square test for sex.

Nonparametric tests were used to examine differences in PA across the five before-school segment definitions, as most variables were not normally distributed according to Shapiro-Wilk testing. First, a Friedman test was conducted for each of the LPA and MVPA variables (minutes per school-day, proportion of segment length, proportion of wear time) among the balanced sample of participants with valid data for all segment definitions. We included analyses of PA minutes and PA relative to segment length and wear time to determine implications of practices identified in Part A (absolute and relative reporting of PA) on adolescents' PA estimates. Finally, to test for differences between pairs of segment definitions, Wilcoxon signed-rank tests were used. Significance was determined at $p<.05$, after applying a Bonferroni correction by multiplying each probability by the number of paired combinations.

RESULTS

Part A

Study and sample characteristics

Seventy-five articles reporting on 69 unique studies were included[1-75] (Figure 1). Information extracted from each study is provided in Supplemental File 2, which also contains the numbered bibliography for citations used in this section. Fifty-nine percent of articles were published in 2015 or later[5-7, 14-16, 21, 22, 24, 25, 28, 30-33, 36-38, 41, 43-50, 52-56, 60-66, 69, 70, 72, 74, 75] (Table 1). The majority of studies were conducted in the US (26 studies)[1, 3, 5-7, 12, 14, 23, 26, 27, 32, 34, 37, 39, 40, 42, 48, 50, 51, 53, 59, 61, 63, 66, 68, 75], followed by England (seven studies)[4, 13, 18, 20, 29, 44, 58]. Fifty-seven percent of studies were conducted with primary/elementary school students[1, 3, 5, 9, 13, 14, 17, 18, 20, 22-24, 26, 27, 29, 31,

[32, 35-37, 40-42, 44, 47, 51-54, 58-64, 66-69], 20% with secondary school students[2, 12, 21, 30, 38, 39, 55, 56, 65, 70-74], and 14% involved both primary and secondary school students[9, 15, 28, 33, 34, 45, 46, 48, 50, 75]. Almost half of included studies (49%) had sample sizes between 100 and 500 participants[4, 11, 12, 14, 15, 20, 23, 27, 28, 30-32, 35, 37, 41-48, 50, 52, 55, 56, 59, 61, 65, 69, 71, 72, 74, 75].

Physical activity measurement and outcome characteristics

Table 2 summarises PA measurement and reporting characteristics. Most studies (94%) measured PA using a single method of assessment. The majority (86%) of studies included a device-based assessment of before-school PA[1, 2, 4, 6, 7, 9, 12-18, 20-24, 26, 28-32, 34-38, 41-48, 50-52, 55, 56, 58-61, 63-75]. Seven studies (10%) included self-report data[15, 23, 27, 48, 53, 54, 62, 67], and seven studies (10%) measured PA using direct observation methods in the school environment[3, 5, 33, 39, 40, 57, 75].

Most studies using device-based measures (76%) reported before-school PA in absolute terms (e.g., total MVPA minutes)[1, 2, 4, 9, 12-16, 18, 20-22, 24, 27, 29, 30, 32, 34-38, 41, 43-48, 51, 52, 55, 56, 59-61, 63, 64, 67-69, 71, 73, 74]. Several device-based studies (42%) included a before-school PA outcome adjusted to a period of time (e.g., proportion of segment length in MVPA)[4, 13, 17, 21, 23, 24, 26, 28, 29, 41, 42, 44, 45, 50, 55, 58, 60, 61, 63-66, 70, 72, 75], while five studies (8%) reported before-school PA relative to accelerometer wear time[6, 7, 31, 46, 48].

Before-school segment definitions

A range of definitions were applied to the before-school segment. Among device-based studies, the before-school segment was most commonly operationalised as commencing at 6:00am and concluding at the start of school, which varied (19%)[9, 12, 15, 29, 31, 45, 46, 51, 52, 61, 72]. Other common approaches included defining the segment as the 60 minutes (12%)[13, 24, 30, 55, 60, 73, 74] or 30 minutes (10%)[4, 19, 20, 49, 50, 59] preceding school start time. Additional studies measured before-school from wake time until school start time (8%)[16, 35, 43, 68, 69] or arrival at school (7%)[17, 22, 56, 67]. Definitions were unable to be determined for five studies (8%)[6, 7, 21, 23, 28], while another three studies (5%) used segments aligned to the school timetable, however specific details about start or end times were not provided[47, 65, 70].

In studies using self-report, recall periods included PA after waking but before going to school[67], 6:00am-school start (reflecting the most common definition within device-based studies)[15], and school arrival time to school start time[67]. Among studies that used direct observation, most used the SOPLAY tool (57%)[3, 5, 39, 40], which requires the first observation to commence up to 40 minutes before school and the last observation to commence 15 minutes before school, occurring on school grounds (McKenzie, 2002).

Segment rationale

Fifty-four articles (72%) did not justify their definitions of the before-school segment[1, 3-14, 16-21, 23, 24, 26-30, 33, 35-40, 42-44, 46-48, 51, 53-57, 61, 62, 65, 67-70, 72, 73]. Eight articles (11%) followed precedents for their segment definition by referring to literature[2, 25, 31, 41, 49, 50, 52, 74]. Seven articles (9%) justified their definition based on suitability for capturing a specific activity type (e.g., active transport)[22, 32, 59, 63, 66, 71, 75], and six articles (8%) provided other reasoning[15, 34, 45, 58, 60, 64], such as having missing data[64] or recording negligible PA for most participants[58] in the time preceding the set segment start time. All segment justifications are reported in Supplemental File 2.

Wear time

While whole-day wear time criteria for device-based studies (e.g., ≥10 hours per day, 3 days per week) were reported in 58% of articles[4, 6-13, 15-20, 22, 29, 31, 34, 35, 37, 38, 41-45, 47, 55, 56, 58-60, 64, 69-71, 74], these articles did not report specific criteria for the before-school segment. Twelve articles (18%) reported before-school wear time criteria[2, 14, 28, 30, 32, 46, 49, 50, 52, 65, 72, 75], while 15 articles (23%) did not report any wear time criteria[1, 21, 23-26, 36, 48, 51, 61, 63, 66-68, 73]. Where reported, before-school wear time criteria most commonly required 30 minutes of valid wear (segment length range: 90-145 minutes) (25%)[32, 46, 72]. Mean wear time in the before-school segment was reported for 10 studies (17%)[2, 14, 32, 46, 47, 49, 50, 56, 72, 75]. Of the studies for which before-school wear time and segment length were both reported, average wear time ranged from 66%[2] to 88%[49] of segment length.

Part B

Segment characteristics and wear time among adolescents

The results of our descriptive analyses of characteristics of the before-school segment definitions are displayed in Table 3. Due to variation in school start times among participating schools (range 8:30am-9:10am), segment length varied by school within the *6:00am-school start (D1), 7:00am-school start (D2),* and *8:00am-school start (D3)* definitions. Four-hundred and seventy-two adolescents provided accelerometer data (mean age 14.9±1.61 years, 40% male). After application of wear time criteria (≥3 days at >50% of segment length), 155 participants provided valid accelerometer data in *D1*, ranging upward to 443 participants in *D5*. Mean days of valid wear was lowest in *D1* (4.2 days) and highest in *D5* (6 days). Mean wear time as a proportion of segment length was also lowest in *D1* (66.2%) and highest in *D5* (97.0%).

Overall, 155 participants met wear time criteria for all five definitions and form the sample for the remainder of the analyses. These participants were younger (-0.4 years, p=.01) and included a greater proportion of girls (χ^2=6.68, p=.01) than participants ineligible for analysis (Supplemental File 3). The two groups did not significantly differ in daily MVPA. Before-school PA data from the full sample are available in Supplemental File 3.

Moderate-to-vigorous physical activity

Table 4 compares time spent in LPA and MVPA across definitions. Average MVPA ranged from 3.7 minutes in *D5* to 9.6 minutes in *D1*. As a proportion of segment duration, mean values ranged from 5.5% of *D1* in MVPA, to 12.5% of *D5* in MVPA. Relative to accelerometer wear, MVPA accounted for 8.4% of wear time in *D1*, through to 12.7% of wear time in *D5*. Box plots showing the distributions of PA data in each segment definition are presented in Figure 2.

There were statistically significant differences in MVPA minutes (χ^2=488.1, p<.001), proportion of segment in MVPA (χ^2=285.6, p<.001), and proportion of wear time in MVPA (χ^2=162.3, p<.001) among definitions. Post-hoc tests (Supplemental File 4) showed significant differences in MVPA by wear time (p<.05) between all pairs of segment definitions except for *D1* and *D2*.

Light physical activity

Average LPA accumulated before-school ranged from 10.1 minutes in *D5* to 35.6 minutes in *D1*. This amounted to a range of 20.6% of total segment length in *D1* to 33.8% of segment length in *D5*. Adjusted for wear time, mean proportions of LPA ranged from 31.4% in *D1* to 34.3% in *D5*.

There were statistically significant differences in LPA minutes (χ^2=572.7, p<.001), proportion of segment in LPA (χ^2=316.7, p<.001), and proportion of wear time in LPA (χ^2=25.1, p<.001) among definitions. Post-hoc tests showed differences in LPA as a proportion of wear time were statistically significant (p<.05) between some segment definition pairs (Supplemental File 4).

DISCUSSION

Our systematic search and review findings highlight large variability in before-school segment definitions reported in studies of child and adolescent PA. While some definitions are more common, substantial variability was identified across studies using the most common approach to measuring PA (device-based), which collectively applied 16 definitions. This supports concerns regarding challenges in drawing meaningful comparisons between outcomes related to before-school PA across studies. We also identified inconsistencies in the level of reporting of segment definitions and device wear time criteria. Further, a rationale for the definition used was lacking in many studies. It is, therefore, appropriate and timely to consider segment-specific measurement and reporting recommendations, particularly as our review has shown an increasing number of publications reporting before-school PA.

Best practice guidelines for studies using accelerometers have emphasised the importance of clearly reporting "decision rules" – how data are processed and analysed – to allow comparisons across studies (Ward et al., 2005). In the manner that accelerometry studies of overall habitual PA are recommended to report their definition of a day and minimum wear time criteria constituting a valid day (Ward et al., 2005), studies reporting PA in segments of the day should also describe segment characteristics, including segment definition and wear time criteria, with appropriate justifications. Our results indicate that for before-school PA, segment definition was reported in most studies, however, specific before-school device wear time criteria were only found in one-fifth

of relevant articles. Most articles reported total day wear time criteria. These wear time criteria reflect common practice and recommendations (Cain et al., 2013), but may not be the most suitable approach for before-school PA studies, where segment-specific criteria could be applied. Commentary to this effect was provided by Noonan et al. (2017), noting that their results may have underestimated segment-specific PA due to low wear time for the segment.

Challenges discussed in the literature regarding measuring before-school PA largely relate to the potential for misclassification of data. Given before-school definitions have been primarily anchored to school start times as an end point, limitations regarding availability of school timetable data, particularly in large scale surveillance studies, may blur boundaries between the before-school segment and the school day (Long et al., 2013; Saint-Maurice et al., 2017). This may lead to classification of before-school time as sedentary, given the predominance of sitting throughout the school day (Egan et al., 2019). Similarly, in several studies, segments were defined by wake times as their start point. This too may present a challenge for data collection and may result in misclassification (i.e., classifying sleep time as sedentary or non-wear time) – a limitation observed in a study that assigned generalised wake times to participants in the absence of sleep data (McLellan et al., 2020). To address compliance issues with device wear and improve the accuracy of sleep detection, automated algorithms have been developed that accurately determine periods of sleep during 24-hour hip or wrist accelerometer wear (see Smith et al., 2020; van Hees et al., 2018, for example). With these developments, 24-hour wear protocols should be considered as an alternate approach to waking-hours protocols, as sleep logs may have poor completion rates and waking wear time is higher through continuous wear (Tudor-Locke et al., 2015).

Limitations were acknowledged among reviewed studies that focused on PA from active transport, pointing to before-school PA measurement challenges that should be considered in future studies. In accelerometer studies that assigned fixed time periods to capture active commuting to school, authors identified that no objective definition of this period exists, and that a generalised time period will lead to the inclusion of non-commuting PA behaviours (Sasayama et al., 2021; Van

Dijk et al., 2014). However, Suzuki et al. (2018) used self-reported school arrival time within their definition of before-school PA. Use of self-report logs is a strategy that may be applied in studies examining active commuting to school, as may combined use of accelerometers and global positioning systems (GPS), recommended to reduce reliance on self-report (Suzuki et al., 2018). Finally, Fairclough et al. (2012) reflected on potential underestimation of segment-specific PA, given the inability of the devices used to measure "upper body movements, water-based activities, and cycling", which may take place before school. The use of monitor wear logs or tools that capture this type of activities may therefore be useful within before-school PA studies.

Less common than device-based measures in the before-school PA literature are self-report and direct observation approaches, however their potential to add value within this segment should be recognised. For instance, some studies exemplified the ability of self-report or direct observation methods to record frequency of specific activity types before school (Going et al., 1999). Although these approaches do have limitations (e.g., self-report measures may be susceptible to recall bias and participant burden) (De Baere et al., 2015; Dollman et al., 2009), these should be weighed against their strengths. The ability to capture environmental and contextual characteristics is one strength of these approaches, enabling examination of where children and adolescents are located (e.g., inside or outside), who they are with (e.g., adults or peers), and what resources are accessible (e.g., presence of supervision and equipment) (Li et al., 2017; McKenzie et al., 2010). As these characteristics include modifiable contextual factors, their assessment can contribute to identification of future before-school intervention opportunities. If feasible, researchers may consider using a combination of PA measurement methods, including direct observation or self-report in conjunction with devices, to contextualise active before-school behaviours.

Our empirical analysis of accelerometer data illuminated potential implications for studies examining before-school PA given the variability in segment definitions and wear time criteria found in our review. Potential wear time issues before school were evidenced by the reduction in the number of participants meeting criteria from the latest-starting, shortest segment definition (*D5*)

to the earliest-starting segment definition requiring the most minutes of wear (*D1*). To meet our wear criteria and contribute data in *D1* (6:00am start), participants needed to attach the device no later than 7:15am-7:35am, and wear it continuously until school start time. While the average school-day wake time of Australian adolescents falls earlier than 7:15am (Olds et al., 2010), high variability of wake time means it is likely that several participants would not wake early enough for inclusion in *D1*, contributing to the lower sample size observed with this definition. Even for participants whose wake time precedes the cut-off, delays in device attachment may result in exclusion from analyses, which may be overcome by implementing a 24-hour device wear protocol (Tudor-Locke et al., 2015).

Some studies applied before-school segment definitions encompassing 60 minutes or less time in the lead up to the start of school. It is plausible that they did so to account for challenges of classifying sleep time and non-wear time, by focusing on segments where most participants are likely to be awake and more compliant with device wear. Alternatively, these studies may have held a conceptual view of the before-school period that focuses on transport-related and on-campus activity, or they may have required a standardised one-hour duration. When interested in segments of the day, a further decision rule that authors should report is the reasoning for selecting the given segment definition or parameters. While some studies included in our review were explicit in their reasoning for only analysing time immediately prior to school, such as to capture travel behaviours, 72% did not justify their definition.

In our comparison of adolescents' before-school PA levels using various definitions, MVPA differences were significant between definitions when expressed as absolute minutes, proportion of segment length, and proportion of wear time. By magnitude of difference, MVPA captured between definitions differed the most when presented as absolute minutes and appeared most similar when expressed as proportion of wear time. The decision to examine PA relative to segment length and wear time was made to align with common practice identified in our systematic search and review (Brusseau et al., 2018; Dessing et al., 2013). This practice addresses the potential for PA minutes to

be confounded by varying segment lengths and wear times and to facilitate comparison across studies.

Differences in LPA were also largest between definitions when expressed as absolute minutes. There was a threefold difference in minutes of LPA between *D1* and *D5*, but only a 3% absolute difference when expressed as a proportion of wear time, again suggesting that minutes of PA is impacted by total wear time. While these results show the potential to exclude 25 minutes of LPA by opting for a shorter before-school segment, it is promising that definitions share more similarity when accounting for wear time and segment time. As scholarly attention directed towards LPA increases (Contardo Ayala et al., 2020; Gråstén et al., 2021), studies examining this behaviour before school should consider potential implications demonstrated here in their selection of segment definition and presentation of data.

Observed differences in PA captured between differentially defined segments, and the variable nature of contextual factors surrounding the before-school period (e.g., school start time, wake time, sunrise time) preclude widespread standardisation of the segment. However, several recommendations for best practice in the measurement and reporting of before-school PA can be derived from this study:

- In addition to reporting absolute PA levels (e.g., minutes), studies should clearly define the before-school segment being used, including sufficient information about segment length, and provide a summary of participant wear time within the segment, to allow for estimates of PA relative to segment length and wear time. Further, sensitivity analyses of PA using other commonly applied before-school segment definitions may be conducted and presented as supplementary material for comparative purposes.
- Segment-specific wear time criteria should be reported when using device-based measures to reduce risk of bias from participants who meet overall wear time criteria but have insufficient wear time before school.

- Authors should justify the selection of before-school segment definition. This may provide important information to inform readers' interpretation of results and for researchers conducting similar research, such as whether decisions were made as a trade-off between segment length and sample size, or to align with a specific aim (e.g., measuring active transport or before-school play on school grounds). A rationale should also be reported for choice of wear time criteria as this can affect PA estimates (Toftager et al., 2013).
- Before-school PA study protocols should include collection of data about participants' wake times over the course of PA measurement. Following a 24-hour wear protocol and applying a wake-time algorithm is one possible approach (Tudor-Locke et al., 2015). Individualised segment start times may then be established, to overcome the issue of misclassifying sleep as non-wear, or, alternatively, excluding waking time.

The combined methods of a systematic search and review with analyses of before-school PA data is a strength of this study. Availability of specific school start times for each school facilitated an additional strength, as these could be applied as the end point to each segment definition to minimise previously observed challenges regarding misclassification of school time. However, participants did not keep sleep logs, preventing our ability to examine another segment definition identified in the literature: *wake time–school start time*. This also limited our ability to distinguish sleep from accelerometer non-compliance, potentially causing the exclusion of participants who adhered to accelerometer wear protocols through the application of wear time criteria relative to standard segment lengths. Further, as our analyses of accelerometer data facilitated an exploratory aim to examine the potential for segment definition selection to influence PA estimates, we drew upon available data from Australian secondary school adolescents only. Before-school PA habits and patterns may differ between primary and secondary school students (resulting from differing school start times and prevalence of active transport, for example), therefore the results from Part B can only be applied to the specific context studied. To expand on our research, it would be valuable

to examine the influence of segment definition selection on before-school PA among primary school students or in settings outside Australia. Additionally, while our aim was not to examine before-school PA levels, nor to generalise recorded PA levels to wider populations, it is worth noting that the group of participants with valid data for all definitions (n=155) included more girls and is likely biased to include those with earlier wake times. Future research should explore this potential for bias, as some participants may be excluded from analyses despite having PA measured for their entire wake period before school. Our sample was also drawn from a wider, non-representative sample. Reported PA levels should therefore be interpreted with caution.

CONCLUSION

This study aimed to examine before-school PA measurement and definition practices, and to compare PA levels in differentially defined before-school segments. Although studies focusing on before-school PA are increasing in number, we found variability in how the before-school segment is represented, and few studies justified their definition. Our data analysis highlighted some challenges that researchers using device-based measures may face in capturing before-school PA. For instance, using protocols that require accelerometer removal for sleep may result in low wear time relative to segment length when definitions with early start times are applied (due to either sleep patterns or delayed device attachment). In acknowledging that challenges exist when measuring before-school PA, we proposed recommendations that may address comparability issues across studies. These recommendations respect that flexibility is needed to fit differing contexts, but encourage detailed reporting to allow researchers to understand other before-school contexts, and how to apply and compare findings. These recommendations should be applied in future research aiming to enhance understanding of the before-school segment, such as identifying correlates of before-school PA and examining effects of targeted interventions to increase before-school PA.

DECLARATIONS

Ethics approval and consent to participate

[redacted] received ethical approval from [redacted], [redacted] and [redacted]. An ethics modification to conduct the current analysis was approved by [redacted] and ratified by [redacted]. Written consent was received from the parents/caregivers of all participants.

Availability of data and materials

The data extraction spreadsheet used for the review component of this study (Part A) is available from the corresponding author on reasonable request. The dataset analysed during Part B of the current study is not publicly available due to ethical restrictions related to participant consent. An ethically compliant dataset may be available on reasonable request.

Competing interests

None declared.

Funding

The [redacted] study received funding from the National Institutes of Health (NIH) (R01 HL111378). [redacted] is supported by Australian Government and [redacted] Research Training Programme Scholarships. [redacted] is supported by a National Health and Medical Research Council Leadership Level 2 Fellowship (APP 1176885).

Authors' contributions

[redacted] conceived the study. [redacted] and [redacted] initiated the [redacted] study. [redacted] conducted the literature search; [redacted] and [redacted] contributed to article screening and selection; [redacted], [redacted] and [redacted] contributed to data extraction and synthesis. [redacted] was involved in processing accelerometer data; [redacted] performed the statistical analysis. [redacted] prepared the first draft of the manuscript; all authors contributed to manuscript revisions and reviewed the final manuscript.

Acknowledgements

The authors would like to thank all participants and research staff for their involvement in the [redacted] study, and [redacted] for assisting with data processing.

References

Adkins, M., Brown, G. A., Heelan, K., Ansorge, C., Shaw, B. S., & Shaw, I. (2013). Can dance exergaming contribute to improving physical activity levels in elementary school children? *Afr J Phys Health Educ Recreat Dance, 19*(3), 576-585. http://search.ebscohost.com/login.aspx?direct=true&db=sph&AN=90642248&site=ehost-live

Aibar, A., Bois, J. E., Zaragoza Casterad, J., Generelo, E., Paillard, T., & Fairclough, S. (2014). Weekday and weekend physical activity patterns of French and Spanish adolescents. *Eur J Sport Sci, 14*(5), 500-509. https://doi.org/10.1080/17461391.2013.829127

Anthamatten, P., Brink, L., Lampe, S., Greenwood, E., Kingston, B., & Nigg, C. (2011). An assessment of schoolyard renovation strategies to encourage children's physical activity. *Int J Behav Nutr Phys Act, 8*, 27. https://doi.org/10.1186/1479-5868-8-27

Arto, G. (2015). Children's segment specific light physical activity across two years of school-based program. *Journal of Physical Education and Sport, 15*(1), 88-95. https://doi.org/10.7752/jpes.2015.01015

Arundell, L., Salmon, J., Veitch, J., O'Connell, E. O., Hinkley, T., & Hume, C. (2013). Standardising the 'after-school' period for children's physical activity and sedentary behaviour. *Health Promot J Austr, 24*, 65-67. https://doi.org/10.1071/HE12910

Bailey, D. P., Fairclough, S. J., Savory, L. A., Denton, S. J., Pang, D., Deane, C. S., & Kerr, C. J. (2012). Accelerometry-assessed sedentary behaviour and physical activity levels during the segmented school day in 10-14-year-old children: the HAPPY study. *Eur J Pediatr, 171*(12), 1805-1813. https://doi.org/10.1007/s00431-012-1827-0

Black, I. E., Menzel, N. N., & Bungum, T. J. (2015). The relationship among playground areas and physical activity levels in children. *J Pediatr Health Care, 29*(2), 156-168. https://doi.org/10.1016/j.pedhc.2014.10.001

Brusseau, T. A., Burns, R. D., & Hannon, J. C. (2018). Physical activity and health-related fitness of adolescents within the juvenile justice system. *Biomed Res Int, 2018*, 9710714. https://doi.org/10.1155/2018/9710714

Brusseau, T. A., Burns, R. D., & Hannon, J. C. (2019). Trends in sedentary and physical activity behaviors in incarcerated adolescent boys during a sports, play, and recreation for kids program. *Am J Health Promot, 33*(5), 760-763. https://doi.org/10.1177/0890117118812666

Cain, K. L., Sallis, J. F., Conway, T. L., Van Dyck, D., & Calhoon, L. (2013). Using accelerometers in youth physical activity studies: a review of methods. *J Phys Act Health, 10*, 437-450.

Carver, A., Timperio, A., & Crawford, D. (2008a). Perceptions of neighborhood safety and physical activity among youth: the CLAN study. *J Phys Act Health, 5*(3), 430-444. https://www.embase.com/search/results?subaction=viewrecord&id=L352141347&from=export

Carver, A., Timperio, A., Hesketh, K., & Crawford, D. (2010a). Are children and adolescents less active if parents restrict their physical activity and active transport due to perceived risk? *Soc Sci Med, 70*(11), 1799-1805. https://doi.org/10.1016/j.socscimed.2010.02.010

Carver, A., Timperio, A., Hesketh, K., & Crawford, D. (2010b). Are safety-related features of the road environment associated with smaller declines in physical activity among youth? *J Urban Health, 87*(1), 29-43. https://doi.org/10.1007/s11524-009-9402-3

Carver, A., Timperio, A. F., & Crawford, D. A. (2008b). Neighborhood road environments and physical activity among youth: The CLAN study. *J Urban Health, 85*(4), 532-544. https://doi.org/10.1007/s11524-008-9284-9

Catellier, D. J., Hannan, P. J., Murray, D. M., Addy, C. L., Conway, T. L., Yang, S., & Rice, J. C. (2005). Imputation of missing data when measuring physical activity by accelerometry. *Med Sci Sports Exerc, 37*(11 SUPPL.), S555-S562. https://doi.org/10.1249/01.mss.0000185651.59486.4e

Cesa, C. C., Sbruzzi, G., Ribeiro, R. A., Barbiero, S. M., de Oliveira Petkowicz, R., Eibel, B., Machado, N. B., Marques, R., Tortato, G., dos Santos, T. J., Leiria, C., Schaan, B. D., & Pellanda, L. C. (2014, Dec). Physical activity and cardiovascular risk factors in children: meta-analysis of randomized clinical trials. *Prev Med, 69*, 54-62. https://doi.org/10.1016/j.ypmed.2014.08.014

Chinapaw, M. J., de Niet, M., Verloigne, M., De Bourdeaudhuij, I., Brug, J., & Altenburg, T. M. (2014). From sedentary time to sedentary patterns: accelerometer data reduction decisions in youth. *PLoS One, 9*(11), e111205. https://doi.org/10.1371/journal.pone.0111205

Contardo Ayala, A. M., Salmon, J., Dunstan, D. W., Arundell, L., & Timperio, A. (2020, Apr 14). Does light-intensity physical activity moderate the relationship between sitting time and adiposity markers in adolescents? *J Sport Health Sci*. https://doi.org/10.1016/j.jshs.2020.04.002

Cooper, A. R., Page, A. S., Wheeler, B. W., Griew, P., Davis, L., Hillsdon, M., & Jago, R. (2010). Mapping the walk to school using accelerometry combined with a global positioning system. *Am J Prev Med, 38*(2), 178-183. https://doi.org/10.1016/j.amepre.2009.10.036

Covidence systematic review software. Veritas Health Innovation. www.covidence.org

Cradock, A. L., Barrett, J. L., Taveras, E. M., Peabody, S., Flax, C. N., Giles, C. M., & Gortmaker, S. L. (2019). Effects of a before-school program on student physical activity levels. *Prev Med Rep, 15*, 100940. https://doi.org/10.1016/j.pmedr.2019.100940

De Baere, S., Lefevre, J., De Martelaer, K., Philippaerts, R., & Seghers, J. (2015). Temporal patterns of physical activity and sedentary behavior in 10-14 year-old children on weekdays. *BMC Public Health, 15*, 791. https://doi.org/10.1186/s12889-015-2093-7

De Vries, S. I., Van Hirtum, H. W., Bakker, I., Hopman-Rock, M., Hirasing, R. A., & Van Mechelen, W. (2009, Apr). Validity and reproducibility of motion sensors in youth: a systematic update. *Med Sci Sports Exerc, 41*(4), 818-827. https://doi.org/10.1249/MSS.0b013e31818e5819

Denstel, K. D., Broyles, S. T., Larouche, R., Sarmiento, O. L., Barreira, T. V., Chaput, J. P., Church, T. S., Fogelholm, M., Hu, G., Kuriyan, R., Kurpad, A., Lambert, E. V., Maher, C., Maia, J., Matsudo, V., Olds, T., Onywera, V., Standage, M., Tremblay, M. S., Tudor-Locke, C., Zhao, P., & Katzmarzyk, P. T. (2015). Active school transport and weekday physical activity in 9-11-year-old children from 12 countries. *Int J Obes Suppl, 5*(Suppl 2), S100-106. https://doi.org/10.1038/ijosup.2015.26

Dessing, D., Pierik, F. H., Sterkenburg, R. P., van Dommelen, P., Maas, J., & de Vries, S. I. (2013). Schoolyard physical activity of 6-11 year old children assessed by GPS and accelerometry. *Int J Behav Nutr Phys Act, 10*, 97. https://doi.org/10.1186/1479-5868-10-97

Dollman, J., Okely, A. D., Hardy, L., Timperio, A., Salmon, J., & Hills, A. P. (2009, Sep). A hitchhiker's guide to assessing young people's physical activity: Deciding what method to use. *J Sci Med Sport, 12*(5), 518-525. https://doi.org/10.1016/j.jsams.2008.09.007

Egan, C. A., Webster, C. A., Beets, M. W., Weaver, R. G., Russ, L., Michael, D., Nesbitt, D., & Orendorff, K. L. (2019). Sedentary time and behavior during school: a systematic review and meta-analysis. *Am J Health Educ, 50*(5), 283-290. https://doi.org/10.1080/19325037.2019.1642814

Fairclough, S. J., Beighle, A., Erwin, H., & Ridgers, N. D. (2012). School day segmented physical activity patterns of high and low active children. *BMC Public Health, 12*, 406. https://doi.org/10.1186/1471-2458-12-406

Fairclough, S. J., Butcher, Z. H., & Stratton, G. (2007). Whole-day and segmented-day physical activity variability of northwest England school children. *Prev Med, 44*(5), 421-425. https://doi.org/10.1016/j.ypmed.2007.01.002

Fairclough, S. J., Butcher, Z. H., & Stratton, G. (2008). Primary school children's health-enhancing physical activity patterns: The school as a significant environment? *Education 3-13, 36*(4), 371-381. https://doi.org/10.1080/03004270801959676

Freedson, P. S., Melanson, E., & Sirard, J. (1998). Calibration of the Computer Science and Applications, Inc. accelerometer. *Med Sci Sports Exerc, 30*(5), 777–781.

Frömel, K., Groffik, D., Mitáš, J., Madarasová Gecková, A., & Csányi, T. (2020). Physical activity recommendations for segments of school days in adolescents: support for health behavior in secondary schools. *Front Public Health, 8*, 527442. https://doi.org/10.3389/fpubh.2020.527442

Gao, Y., Wang, J. J., Lau, P. W. C., & Ransdell, L. (2015). Pedometer-determined physical activity patterns in a segmented school day among Hong Kong primary school children. *J Exerc Sci Fit, 13*(1), 42-48. https://doi.org/10.1016/j.jesf.2015.03.002

Going, S. B., Levin, S., Harrell, J., Stewart, D., Kushi, L., Cornell, C. E., Hunsberger, S., Corbin, C., & Sallis, J. (1999). Physical activity assessment in American Indian schoolchildren in the pathways study. *Am J Clin Nutr, 69*(4 SUPPL.), 788S-995S. https://doi.org/10.1093/ajcn/69.4.788s

Grant, M. J., & Booth, A. (2009, Jun). A typology of reviews: an analysis of 14 review types and associated methodologies. *Health Info Libr J, 26*(2), 91-108. https://doi.org/10.1111/j.1471-1842.2009.00848.x

Gråstén, A. (2015). Children's segment specific moderate to vigorous physical activity through a school-initiated physical activity program. *Balt J Health Phys Act, 7*(2), 19-32. http://search.ebscohost.com/login.aspx?direct=true&db=sph&AN=116295194&site=ehost-live

Gråstén, A., Huhtiniemi, M., Hakonen, H., & Jaakkola, T. (2021). Development of accelerometer-based light to vigorous physical activity in fitness profiles of school- aged children. *Scand J Med Sci Sports, 31*, 2343–2355. https://doi.org/10.1111/sms.14056

Hager, R. L. (2006). Television viewing and physical activity in children. *J Adolesc Health, 39*(5), 656-661. https://doi.org/10.1016/j.jadohealth.2006.04.020

Heelan, K. A., Donnelly, J. E., Jacobsen, D. J., Mayo, M. S., Washburn, R., & Greene, L. (2005). Active commuting to and from school and BMI in elementary school children-preliminary data. *Child Care Health Dev, 31*(3), 341-349. https://doi.org/10.1111/j.1365-2214.2005.00513.x

Hubáčková, R., Groffik, D., Skrzypnik, L., & Frömel, K. (2016). Physical activity and inactivity in primary and secondary school boys' and girls' daily program. *Acta Gymnica, 46*(4), 193-200. https://doi.org/10.5507/ag.2016.020

Jago, R., Fox, K. R., Page, A. S., Brockman, R., & Thompson, J. L. (2010). Physical activity and sedentary behaviour typologies of 10-11 year olds. *Int J Behav Nutr Phys Act, 7*. https://doi.org/10.1186/1479-5868-7-59

Kek, C. C., García Bengoechea, E., Spence, J. C., & Mandic, S. (2019). The relationship between transport-to-school habits and physical activity in a sample of New Zealand adolescents. *J Sport Health Sci, 8*(5), 463-470. https://doi.org/10.1016/j.jshs.2019.02.006

Kidokoro, T., Tian, X., Fuku, N., Waiganjo, L. B., Rintaugu, E. G., Kigaru, M. D., & Mwangi, F. M. (2021). Segmented physical activity and sedentary behavior patterns among children in Maasai village and Nairobi city. *Am J Hum Biol*, e23649. https://doi.org/10.1002/ajhb.23649

Lee, S., Lee, C., Nam, J. W., Abbey-Lambertz, M., & Mendoza, J. (2020). School walkability index: application of environmental audit tool and GIS. *J Transp Health, 18*. https://doi.org/10.1016/j.jth.2020.100880

Li, R., Sit, C. H., Yu, J. J., Sum, R. K., Wong, S. H., Cheng, K. C., & McKenzie, T. L. (2017). Children with physical disabilities at school and home: physical activity and contextual characteristics. *Int J Environ Res Public Health, 14*(7). https://doi.org/10.3390/ijerph14070687

Long, M. W., Sobol, A. M., Cradock, A. L., Subramanian, S. V., Blendon, R. J., & Gortmaker, S. L. (2013). School-day and overall physical activity among youth. *Am J Prev Med, 45*(2), 150-157. https://doi.org/10.1016/j.amepre.2013.03.011

Loucaides, C. A. (2018). Seasonal differences in segmented-day physical activity and sedentary behaviour in primary school children. *Early Child Dev Care, 188*(3), 410-420. https://doi.org/10.1080/03004430.2016.1226292

Loucaides, C. A., & Jago, R. (2008). Differences in physical activity by gender, weight status and travel mode to school in Cypriot children. *Prev Med, 47*(1), 107-111. https://doi.org/10.1016/j.ypmed.2008.01.025

Matisziw, T. C., Nilon, C. H., Wilhelm Stanis, S. A., LeMaster, J. W., McElroy, J. A., & Sayers, S. P. (2016). The right space at the right time: the relationship between children's physical activity and land use/land cover. *Landsc Urban Plan, 151*, 21-32. https://doi.org/10.1016/j.landurbplan.2016.03.006

Mattocks, C., Ness, A. R., Leary, S. D., Tilling, K., Blair, S. N., Shield, J., Deere, K., Saunders, J., Krikby, J., Davey Smith, G., Wells, J., Wareham, N., Reilly, J. J., & Riddoch, C. J. (2008). Use of accelerometers in a large field-based study of children: protocols, design issues, and effects on precision. *J Phys Act Health, 5*, S98-S111.

McCrorie, P. R., Duncan, E., Granat, M. H., & Stansfield, B. W. (2015). Seasonal variation in the distribution of daily stepping in 11-13 year old school children. *Int J Exerc Sci, 8*(4).

McKenzie, T. L. (2002). *System for Observing Play and Leisure Activity in Youth (SOPLAY)*. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.485.669&rep=rep1&type=pdf

McKenzie, T. L., Crespo, N. C., Baquero, B., & Elder, J. P. (2010). Leisure-time physical activity in elementary schools: analysis of contextual conditions. *J Sch Health, 80*(10), 470-477. https://doi.org/10.1111/j.1746-1561.2010.00530.x

McKenzie, T. L., Marshall, S. J., Sallis, J. F., & Conway, T. L. (2000). Leisure-time physical activity in school environments: an observational study using SOPLAY. *Prev Med, 30*(1), 70-77. https://doi.org/10.1006/pmed.1999.0591

McLellan, G., Arthur, R., Donnelly, S., & Buchan, D. S. (2020). Segmented sedentary time and physical activity patterns throughout the week from wrist-worn ActiGraph GT3X+

accelerometers among children 7-12 years old. *J Sport Health Sci, 9*(2), 179-188. https://doi.org/10.1016/j.jshs.2019.02.005

McMahon, E. M., Corcoran, P., O'Regan, G., Keeley, H., Cannon, M., Carli, V., Wasserman, C., Hadlaczky, G., Sarchiapone, M., Apter, A., Balazs, J., Balint, M., Bobes, J., Brunner, R., Cozman, D., Haring, C., Iosue, M., Kaess, M., Kahn, J. P., Nemes, B., Podlogar, T., Postuvan, V., Saiz, P., Sisask, M., Tubiana, A., Varnik, P., Hoven, C. W., & Wasserman, D. (2017, Jan). Physical activity in European adolescents and associations with anxiety, depression and well-being. *Eur Child Adolesc Psychiatry, 26*(1), 111-122. https://doi.org/10.1007/s00787-016-0875-9

Miller, W. C., Redmond, J. G., & Vaux-Bjerke, A. T. (2013). Activity patterns and perceptions about active transport to school. *Am J Health Behav, 37*(2), 190-198. https://doi.org/10.5993/ajhb.37.2.6

Mooses, K., Mäestu, J., Riso, E. M., Hannus, A., Mooses, M., Kaasik, P., & Kull, M. (2016). Different methods yielded two-fold difference in compliance with physical activity guidelines on school days. *PLoS One, 11*(3), e0152323. https://doi.org/10.1371/journal.pone.0152323

Noonan, R. J., Boddy, L. M., Kim, Y., Knowles, Z. R., & Fairclough, S. J. (2017). Comparison of children's free-living physical activity derived from wrist and hip raw accelerations during the segmented week. *J Sports Sci, 35*(21), 2067-2072. https://doi.org/10.1080/02640414.2016.1255347

Olds, T., Maher, C., Blunden, S., & Matricciani, L. (2010). Normative data on the sleep habits of Australian children and adolescents. *SLEEP, 33*(10), 1381-1388.

Parker, K. E., Salmon, J., Brown, H. L., Villanueva, K., & Timperio, A. (2019). Typologies of adolescent activity related health behaviours. *J Sci Med Sport, 22*, 319-323. https://doi.org/10.1016/j.jsams.2018.08.015

Poitras, V. J., Gray, C. E., Borghese, M. M., Carson, V., Chaput, J. P., Janssen, I., Katzmarzyk, P. T., Pate, R. R., Connor Gorber, S., Kho, M. E., Sampson, M., & Tremblay, M. S. (2016, Jun). Systematic review of the relationships between objectively measured physical activity and health indicators in school-aged children and youth. *Appl Physiol Nutr Metab, 41*(6 Suppl 3), S197-239. https://doi.org/10.1139/apnm-2015-0663

Qi, J., Xu, J. W., & Shao, W. (2020). Physical activity of children with visual impairments during different segments of the school day. *Int J Environ Res Public Health, 17*(18). https://doi.org/10.3390/ijerph17186897

Remmers, T., Van Kann, D., Kremers, S., Ettema, D., de Vries, S. I., Vos, S., & Thijs, C. (2020). Investigating longitudinal context-specific physical activity patterns in transition from primary to secondary school using accelerometers, GPS, and GIS. *Int J Behav Nutr Phys Act, 17*(1), 66. https://doi.org/10.1186/s12966-020-00962-3

Ridgers, N. D., Timperio, A., Cerin, E., & Salmon, J. (2015). Within- and between-day associations between children's sitting and physical activity time. *BMC Public Health, 15*, 950. https://doi.org/10.1186/s12889-015-2291-3

Saint-Maurice, P. F., Bai, Y., Vazou, S., & Welk, G. (2018). Youth physical activity patterns during school and out-of-school time. *Children (Basel), 5*(9). https://doi.org/10.3390/children5090118

Saint-Maurice, P. F., Kim, Y., & Welk, G. J. (2017). Evidence for data missing at random in youth physical activity monitoring research. *J Sports Sci, 35*(5), 484-490. https://doi.org/10.1080/02640414.2016.1173719

Saint-Maurice, P. F., & Welk, G. J. (2015). Validity and calibration of the Youth Activity Profile. *PLoS One, 10*(12), e0143949. https://doi.org/10.1371/journal.pone.0143949

Saksvig, B. I., Catellier, D. J., Pfeiffer, K., Schmitz, K. H., Conway, T., Going, S., Ward, D., Strikmiller, P., & Treuth, M. S. (2007). Travel by walking before and after school and

physical activity among adolescent girls. *Arch Pediatr Adolesc Med, 161*(2), 153-158. https://doi.org/10.1001/archpedi.161.2.153

Sasayama, K., Watanabe, M., & Ogawa, T. (2021). Walking to/from school is strongly associated with physical activity before and after school and whole-day in schoolchildren: A pilot study. *J Transp Health, 21*. https://doi.org/10.1016/j.jth.2021.101077

Schlange, K., Franzen-Castle, L., Walther, A., Dunker, T., & Krehbiel, M. (2021). Parent/caregiver perceptions of youth health outcomes after participating in the WeCook: Fun With Food and Fitness program. *Health Educ Behav, 48*(2), 140-149. https://doi.org/10.1177/1090198120969379

Sheldrick, M. P. R., Tyler, R., Mackintosh, K. A., & Stratton, G. (2018). Relationship between sedentary time, physical activity and multiple lifestyle factors in children. *J Funct Morphol Kinesiol, 3*(1). https://doi.org/10.3390/jfmk3010015

Silva, P., Sousa, M., Sá, C., Ribeiro, J., & Mota, J. (2015). Physical activity in high school during 'free-time' periods. *Eur Phy Educ Rev, 21*(2), 135-148. https://doi.org/10.1177/1356336X14555295

Šimůnek, A., Dygrýn, J., Jakubec, L., Neuls, F., Frömel, K., & Welk, G. J. (2019). Validity of Garmin Vívofit 1 and Garmin Vívofit 3 for school-based physical activity monitoring. *Pediatr Exerc Sci, 31*(1), 130-136. https://doi.org/10.1123/pes.2018-0019

Sit, C. H., McKenzie, T. L., Cerin, E., McManus, A., & Lian, J. (2013). Physical activity for children in special school environment. *Hong Kong Med J, 19 Suppl 4*, 42-44.

Smith, C., Galland, B., Taylor, R., & Meredith-Jones, K. (2020, 2020-January-14). ActiGraph GT3X+ and Actical Wrist and Hip Worn Accelerometers for Sleep and Wake Indices in Young Children Using an Automated Algorithm: Validation With Polysomnography [Original Research]. *Frontiers in Psychiatry, 10*. https://doi.org/10.3389/fpsyt.2019.00958

StataCorp. (2021). *Stata Statistical Software: Release 17.* In StataCorp LLC.

Steele, R. M., van Sluijs, E. M., Sharp, S. J., Landsbaugh, J. R., Ekelund, U., & Griffin, S. J. (2010). An investigation of patterns of children's sedentary and vigorous physical activity throughout the week. *Int J Behav Nutr Phys Act, 7*, 88. https://doi.org/10.1186/1479-5868-7-88

Stevens, R. B., & Brown, B. B. (2011). Walkable new urban LEED_Neighborhood-Development (LEED-ND) community design and children's physical activity: selection, environmental, or catalyst effects? *Int J Behav Nutr Phys Act, 8*, 139. https://doi.org/10.1186/1479-5868-8-139

Strugnell, C., Turner, K., Malakellis, M., Hayward, J., Foster, C., Millar, L., & Allender, S. (2016). Composition of objectively measured physical activity and sedentary behaviour participation across the school-day, influence of gender and weight status: cross-sectional analyses among disadvantaged Victorian school children. *BMJ Open, 6*(9), e011478. https://doi.org/10.1136/bmjopen-2016-011478

Strutz, E., Browning, R., Smith, S., Lohse, B., & Cunningham-Sabo, L. (2018). Accelerometry-derived physical activity correlations between parents and their fourth-grade child are specific to time of day and activity level. *J Phys Act Health, 15*(6), 440-447. https://doi.org/10.1123/jpah.2016-0645

Štveráková, T., Jačisko, J., Busch, A., Šafářová, M., Kolář, P., & Kobesová, A. (2021). The impact of COVID-19 on physical activity of Czech children. *PLoS One, 16*(7), e0254244. https://doi.org/10.1371/journal.pone.0254244

Stylianou, M., van der Mars, H., Kulinna, P. H., Adams, M. A., Mahar, M., & Amazeen, E. (2016). Before-school running/walking club and student physical activity levels: an efficacy study. *Res Q Exerc Sport, 87*(4), 342-353. https://doi.org/10.1080/02701367.2016.1214665

Suzuki, I., Okuda, M., Tanaka, M., Inoue, S., Tanaka, S., & Tanaka, C. (2018). Variability in school children's activity occurs in the recess and before-school periods. *Pediatr Int, 60*(8), 727-734. https://doi.org/10.1111/ped.13616

Svozil, Z., Frömel, K., Chmelík, F., Jakubec, L., Groffik, D., & Šafář, M. (2015). Mental load and its compensation by physical activity in adolescents at secondary schools. *Cent Eur J Public Health, 23 Suppl*, S44-49. https://doi.org/10.21101/cejph.a4186

The EndNote Team. (2013). *EndNote.* In Clarivate Analytics.

Toftager, M., Kristensen, P. L., Oliver, M., Duncan, S., Breum Christiansen, L., Boyle, E., Christian Brønd, J., & Troelsen, J. (2013). Accelerometer data reduction in adolescents: effects on sample retention and bias. *Int J Behav Nutr Phys Act, 10*. https://doi.org/https://doi.org/10.1186/1479-5868-10-140

Tompkins, C. L., Flanagan, T., Lavoie, J., 2nd, & Brock, D. W. (2015). Heart rate and perceived exertion in healthy weight and obese children during a self-selected physical activity program. *J Phys Act Health, 12*(7), 976-981. https://doi.org/10.1123/jpah.2013-0374

Tremblay, M. S., Inman, J. W., & Willms, J. D. (2001). Preliminary evaluation of a video questionnaire to assess activity levels of children. *Med Sci Sports Exerc, 33*(12), 2139-2144. https://doi.org/10.1097/00005768-200112000-00025

Trost, S. G., Pate, R. R., Sallis, J. F., Freedson, P. S., Taylor, W. C., Dowda, M., & Sirard, J. (2002). Age and gender differences in objectively measured physical activity in youth. *Med Sci Sports Exerc, 34*(2), 350-355.

Tudor-Locke, C., Barreira, T. V., Schuna, J. M., Jr., Mire, E. F., Chaput, J. P., Fogelholm, M., Hu, G., Kuriyan, R., Kurpad, A., Lambert, E. V., Maher, C., Maia, J., Matsudo, V., Olds, T., Onywera, V., Sarmiento, O. L., Standage, M., Tremblay, M. S., Zhao, P., Church, T. S., Katzmarzyk, P. T., & Group, I. R. (2015, Feb 11). Improving wear time compliance with a 24-hour waist-worn accelerometer protocol in the International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE). *Int J Behav Nutr Phys Act, 12*, 11. https://doi.org/10.1186/s12966-015-0172-x

Tudor-Locke, C., Lee, S. M., Morgan, C. F., Beighle, A., & Pangrazi, R. P. (2006). Children's pedometer-determined physical activity during the segmented school day. *Med Sci Sports Exerc, 38*(10), 1732-1738. https://doi.org/10.1249/01.mss.0000230212.55119.98

Uys, M., Broyles, S. T., C, E. D., Hendricks, S., Rae, D., Naidoo, N., Katzmarzyk, P. T., & Lambert, E. V. (2016). Perceived and objective neighborhood support for outside of school physical activity in South African children. *BMC Public Health, 16*, 462. https://doi.org/10.1186/s12889-016-2860-0

Valach, P., Vašíčková, J., Frömel, K., Jakubec, L., Chmelík, F., & Svozil, Z. (2020). Is academic achievement reflected in the level of physical activity among adolescents? *Journal of Physical Education and Sport, 20*(1), 186-195. https://doi.org/10.7752/jpes.2020.01025

Van Dijk, M. L., De Groot, R. H. M., Van Acker, F., Savelberg, H. H. C. M., & Kirschner, P. A. (2014). Active commuting to school, cognitive performance, and academic achievement: An observational study in Dutch adolescents using accelerometers. *BMC Public Health, 14*(1). https://doi.org/10.1186/1471-2458-14-799

van Hees, V. T., Sabia, S., Jones, S. E., Wood, A. R., Anderson, K. N., Kivimäki, M., Frayling, T. M., Pack, A. I., Bucan, M., Trenell, M. I., Mazzotti, D. R., Gehrman, P. R., Singh-Manoux, B. A., & Weedon, M. N. (2018, 2018/08/28). Estimating sleep parameters using an accelerometer without sleep diary. *Scientific Reports, 8*(1), 12975. https://doi.org/10.1038/s41598-018-31266-z

Van Kann, D. H. H., Adank, A. M., van Dijk, M. L., Remmers, T., & Vos, S. B. (2019). Disentangling physical activity and sedentary behavior patterns in children with low motor competence. *Int J Environ Res Public Health, 16*(20). https://doi.org/10.3390/ijerph16203804

Voss, C., Winters, M., Frazer, A. D., & McKay, H. A. (2014). They go straight home - don't they? Using global positioning systems to assess adolescent school-travel patterns. *J Transp Health, 1*(4), 282-287. https://doi.org/10.1016/j.jth.2014.09.013

Ward, D. S., Evenson, K. R., Vaughn, A., Rodgers, A. B., & Troiano, R. P. (2005, Nov). Accelerometer use in physical activity: best practices and research recommendations. *Med Sci Sports Exerc*, *37*(11 Suppl), S582-588. https://doi.org/10.1249/01.mss.0000185292.71933.91

White, B., Bengoechea, E. G., Spence, J. C., Coppell, K. J., & Mandic, S. (2021). Comparison of physical activity patterns across large, medium and small urban areas and rural settings in the Otago Region, New Zealand. *N Z Med J*, *134*(1534), 51-65.

Whooten, R. C., Horan, C., Cordes, J., Dartley, A. N., Aguirre, A., & Taveras, E. M. (2020). Evaluating the implementation of a before-school physical activity program: a mixed-methods approach in Massachusetts, 2018. *Prev Chronic Dis*, *17*, E116. https://doi.org/10.5888/pcd17.190445

Woodforde, J., Alsop, T., Salmon, J., Gomersall, S., & Stylianou, M. (2022). Effects of school-based before-school physical activity programmes on children's physical activity levels, health and learning-related outcomes: a systematic review. *Br J Sports Med*, *56*(13), 740-754. https://doi.org/10.1136/bjsports-2021-104470

World Health Organization. (2018). *Global action plan on physical activity 2018–2030: more active people for a healthier world*.