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

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Physical activity (PA) among children and adolescents is often reported by time segments centered 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 analyzed accelerometer data from Australia (n = 472, mean age 14.9 years, 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 min prior to school; n = 443) to the earliest-starting definition (6:00 a.m.–school start; n = 155), implying that for many participants, accelerometer wear was low in the early hours due to sleep or noncompliance. Statistically significant differences in light and moderate-to-vigorous PA (mean minutes/school day, proportion of segment length, and 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 individualized segment start times and minimize risk of data misclassification.

Keywords: accelerometer, adolescents, children, morning

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 operationalized 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 standardized definition of the after-school segment has been proposed (i.e., end of school to 6:00 p.m.; 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 standardized or conceptualized, 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 conceptualization and description of before-school PA contribute to challenges in making comparisons and synthesizing 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 the following: (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 synthesize 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 “combine strengths of critical review with a comprehensive search process” and “typically address broad questions to produce ‘best evidence synthesis.’” This review method, which distinguishes itself from systematic review by not requiring quality assessment, is appropriate for synthesizing 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 (Supplementary Material S1 [available online]) was finalized 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 (a) sedentary behavior only, (b) PA for a segment overlapping with school time, or (c) 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, n.d.) for independent title/abstract and subsequently full-text screening by two reviewers (Woodforde and Stylianou). Disagreements at either screening stage (n = 48 at title/abstract and 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 (Woodforde and Browning): publication year, country, study design, sample size (school and 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 rigor, the following characteristics that are critical to the study’s first aim were independently extracted by two reviewers (Woodforde and Browning): definition applied to the before-school segment, and justification provided for the definition. Disagreements were resolved through discussion. All characteristics were descriptively synthesized.

Part B

Context and Participants

The empirical component of this study used cross-sectional data from the NEighborhood Activity in Youth (NEArbY) study, collected between August 2014 and December 2015. Participants were adolescents from schools selected from each of four stratifications of walkability and income within Melbourne, 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 PA Measurement

Participants were asked to wear an ActiGraph model GT3X+ accelerometer on their waist during waking hours for 8 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 hr and no weekend days with 8 hr). Periods with ≥60 min of consecutive zero counts were classified as nonwear 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 ≥2,220 counts per minute [cpm] to ≥3,499 cpm, LPA: >100 cpm, and less than MVPA threshold; Trost et al., 2002). For participants aged >18 years, Freedson adult cut points were used (MVPA: ≥1,952 cpm, LPA: >100 cpm and less than MVPA threshold; Freedson et al., 1998).

Data Processing

Using a customized 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) 6:00 a.m.–school start, Definition 2 (D2) 7:00 a.m.–school start, Definition 3 (D3) 8:00 a.m.–school start, Definition 4 (D4) 60 min prior to school start time, and Definition 5 (D5) 30 min 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 three 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 summarized 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–Wilks testing. First, a Friedman test was conducted for each of the LPA and MVPA variables (minutes per school day, proportion of segment length, and 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 included1–75 (Figure 1). Information extracted from each study is provided in Supplementary Material S2 (available online), which also contains the numbered bibliography for citations used in this section. Fifty-nine percent of articles were published in 2015 or later6–7,14–16,21,22,24,25,28,30–33,36–38,41,43–50,52–56,60–66,69,70,72,74,75 (Table 1). The majority of studies were conducted in the United States (26 studies)1,3,5–7,12,14,19,23,26,27,32,34,37,39,40,42,48,50,51,53,59,61,63,66,68,75, followed by England (seven studies)4,13,18,20,29,44,58. Fifty-seven percent of studies were conducted with primary/elementary school students1,3,5–9,13,14,17,18,20,22–24,26,27,29,31,32,35–37,40,42,44,47,51–54,58–64,66–69,20% with secondary school students2,12,13,21,30,38,39,55,65,70–74, and 14% involved both primary and secondary school students9,15,28,33,45,46,48,50,73. Almost half of included studies (49%) had sample sizes between 100 and 500 participants4,11,12,14,15,20,23,27,28,30–32,35,37,41–48,50,52,55,56,59,61,65,69,71,72,74,75.

PA Measurement and Outcome Characteristics

Table 2 summarizes 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 PA1,2,4,6,7,9,12–18,20–22,24,27,29,30,32–34,38,41–48,50–52,55,56,58–61,63–75. Seven studies (10%) included self-report data15,23,27,48,53,54,62,67, and seven studies (10%) measured PA using direct observation methods in the school environment12,15,33,39,40,57,75.

Most studies using device-based measures (76%) reported before-school PA in absolute terms (e.g., total MVPA minutes1,2,4,9,12–16,18–20–22,24,27,29,30,32–34,38,41–43–48,51,52,53,56,59–61,63,64,67–69,71,73,74. 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)1,3,13,17,21,23,24,26,28,29,41,42,44,45,50,55,58,60,61,63–66,67,70,72,75, while five studies (8%) reported before-school PA relative to accelerometer wear time6,7,31,46,48.

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 operationalized as commencing at 6:00 a.m. and concluding at the start of school, which varied (19%)6,12,15,29,31,45,46,51,52,61,72. Other common approaches included defining the segment as the 60 min (12%)3,14,24,30,55,60,73,74 or 30 min (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 provided47,65,70.

In studies using self-report, recall periods included PA after waking but before going to school67, 6:00 a.m.–school start (reflecting the most common definition within device-based studies)15, and school arrival time to school start time67. Among studies that used direct observation, most used the System for Observing Play and Leisure Activity in Youth tool (57%)1,5,39,40, which requires the first observation to commence up to 40 min before school and the last observation to commence 15 min before school, occurring on school grounds (McKenzie, 2002).

Segment Rationale

Fifty-four articles (72%) did not justify their definitions of the before-school segment1,3,13–14,16–21,23,24,26–30,33,35–40,42–44,46–48,51,53–57,61,62,65,67–70,72,73. Eight articles (11%) followed precedents for their segment definition by referring to literature2,22,31,41,49,50,72,74. Seven articles (9%) justified their definition based on suitability for capturing a specific activity type (e.g., active transport)22,32,39,63,66,71,75, and six articles (8%) provided other reasoning15,34,45,58,60,64, such as having
missing data or recording negligible PA for most participants in the time preceding the set segment start time. All segment justifications are reported in Supplementary Material S2 (available online).

Wear Time

While whole-day wear time criteria for device-based studies (e.g., ≥10 hr/day, 3 days/week) were reported in 58% of articles, these articles did not report specific criteria for the before-school segment. Twelve articles (18%) reported before-school wear time criteria, while 15 articles (23%) did not report any wear time criteria. Where reported, before-school wear time criteria most commonly required 30 min of valid wear (segment length range: 90–145 min; 25%), while 15 articles (23%) did not report any wear time criteria. Where reported, before-school wear time criteria most commonly required 30 min of valid wear (segment length range: 90–145 min; 25%).

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: 8:30 a.m.–9:10 a.m.), segment length varied by school within D1, D2, and 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 (≥23 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 were 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 (χ² = 6.68, p = .01) than participants ineligible for analysis (Supplementary Material S3 [available online]). The two groups did not significantly differ in daily MVPA. Before-school PA data from the full sample are available in Supplementary Material S3 (available online).

Moderate-to-Vigorous Physical Activity

Table 4 compares time spent in LPA and MVPA across definitions. Average MVPA ranged from 3.7 min in D5 to 9.6 min 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 ($\chi^2 = 488.1, p < .001$), proportion of segment in MVPA ($\chi^2 = 285.6, p < .001$), and proportion of wear time in MVPA ($\chi^2 = 162.3, p < .001$) among definitions. Post hoc tests (Supplementary Material S4 [available online]) 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 min in D5 to 35.6 min 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 ($\chi^2 = 572.7, p < .001$), proportion of segment in LPA ($\chi^2 = 316.7, p < .001$), and proportion of wear time in LPA ($\chi^2 = 25.1, p < .001$) among definitions. Post hoc tests showed differences in LPA as a proportion of wear time was statistically significant ($p < .05$) between some segment definition pairs (Supplementary Material S4 [available online]).

**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...
Table 2 Summary of Before-School PA Measurement and Reporting Characteristics

<table>
<thead>
<tr>
<th>PA measurementa</th>
<th>n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Device-based</td>
<td>59 (85.5%)</td>
</tr>
<tr>
<td>Self-report</td>
<td>7 (10.1%)</td>
</tr>
<tr>
<td>Direct observation</td>
<td>7 (10.1%)</td>
</tr>
</tbody>
</table>

PA outcome reported

Studies using device-based measures (n = 59)

Absolute (e.g., MVPA minutes and total steps)

Relative to unit of time (e.g., proportion of defined before-school segment in MVPA, LPA minutes per hour, and PA counts per minute)

Relative to wear time (e.g., proportion of time spent wearing accelerometer in MVPA)

Studies using self-report methods (n = 7)

Absolute (e.g., MVPA minutes, number of days in previous week engaged in PA, and PA questionnaire index score)

Studies using direct observation methods (n = 7)

Relative to wear time (e.g., proportion of time spent wearing accelerometer in MVPA)

Absolute (e.g., number of observed children engaged in MPA and MVPA minutes)

Before-school definitiona

Studies using device-based measures (n = 59)

6:00 a.m.–school start time (variable: 7:59 a.m., 8:00 a.m., 8:20 a.m., 8:30 a.m., 8:45 a.m., 8:59 a.m., and 9:00 a.m.)

60 min prior to school start time (variable: 8:30 a.m., 8:59 a.m., and 9:00 a.m.)

30 min prior to school start time

Wake time–school start time

Wake time/putting on accelerometer–arrival at school

Intermediate time periods (e.g., 7:00 a.m.–8:30 a.m. and school start 9:00 a.m.)

2 hr prior to school start time

Arrival at school–school start time

90 min prior to school start time

12:00 a.m.–school start time

6:30 a.m.–school start time

Multiple hourly segments

7:15 a.m.–school start (8:30 a.m.)

5:00 a.m.–8:00 a.m.

“Before coming to school”–school start

According to school timetable or written segment times (otherwise not reported)

Not reported

Studies using self-report methods (n = 7)

After waking, but before going to school

6:00 a.m.–school start

6:00 a.m.–8:00 a.m.

After arriving at school, but before class starting

SAPAC protocol: Time from waking until school start bell

CHAT protocol: Before lessons started

PAQ-C (Czech) protocol: Morning before school

Not reported

(continued)
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 emphasized the importance of clearly reporting “decision rules”—how data are processed and analyzed—to allow comparisons across studies (Ward et al., 2005). In the manner that accelerometer 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...
<table>
<thead>
<tr>
<th>Table 3  Segment Characteristics and Wear Time</th>
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<tbody>
<tr>
<td>Definition 1 (6:00 a.m. to school start time)</td>
</tr>
<tr>
<td>Definition 2 (7:00 a.m. to school start time)</td>
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<tr>
<td>Definition 3 (8:00 a.m. to school start time)</td>
</tr>
<tr>
<td>Definition 4 (60 min prior to school start time)</td>
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<tr>
<td>Definition 5 (30 min prior to school start time)</td>
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</tbody>
</table>

| n (% of sample) meeting wear criteria | 155 (32.8%) | 335 (71.0%) | 438 (92.8%) | 434 (91.9%) | 443 (93.9%) |
| Age (years) | Mean | 14.7 | 14.8 | 14.9 | 14.9 | 14.9 |
| | SD | 1.57 | 1.58 | 1.62 | 1.62 | 1.61 |
| Sex, n (%) | Female | 100 (64.5%) | 202 (60.3%) | 256 (58.4%) | 255 (58.8%) | 259 (58.5%) |
| | Male | 49 (31.6%) | 119 (35.5%) | 167 (38.1%) | 164 (37.8%) | 169 (38.1%) |
| | Not recorded | 6 (3.9%) | 14 (4.2%) | 15 (3.4%) | 15 (3.5%) | 15 (3.4%) |
| Segment length (min) | Mean | 172.8 | 113.6 | 53.9 | — | — |
| | SD | 9.87 | 9.15 | 9.17 | — | — |
| | Range | 150–190 | 90–130 | 30–70 | — | — |
| Valid accelerometer wear (days >50% wear) | Mean | 4.2 | 5.0 | 5.8 | 5.8 | 6 |
| | SD | 1.13 | 1.34 | 1.31 | 1.34 | 1.28 |
| | Range | 3–9 | 3–9 | 3–12 | 3–12 | 3–12 |
| Accelerometer wear (min per day) | Mean | 114.4 | 86.3 | 50.1 | 55.1 | 29.1 |
| | SD | 19.31 | 14.00 | 8.55 | 4.87 | 1.46 |
| Accelerometer wear (% segment length) | Mean | 66.2 | 76.1 | 93.4 | 91.9 | 97.0 |
| | SD | 10.59 | 11.34 | 7.50 | 8.11 | 4.86 |

Note. All summary data presented in this table have been calculated after application of the 3-day minimum wear requirement.
Table 4  Physical Activity Levels by Differential Definitions of Before-School Segment

<table>
<thead>
<tr>
<th></th>
<th>Definition 1 (6:00 a.m. to school start time)</th>
<th>Definition 2 (7:00 a.m. to school start time)</th>
<th>Definition 3 (8:00 a.m. to school start time)</th>
<th>Definition 4 (60 min prior to school start time)</th>
<th>Definition 5 (30 min prior to school start time)</th>
<th>χ²</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPA (min per day)</td>
<td>Mean (SD)</td>
<td>35.6 (10.61)</td>
<td>31.6 (8.47)</td>
<td>17.2 (5.38)</td>
<td>19.7 (5.32)</td>
<td>10.1 (3.13)</td>
</tr>
<tr>
<td></td>
<td>95% CI</td>
<td>[33.98, 37.42]</td>
<td>[30.34, 33.01]</td>
<td>[16.35, 18.05]</td>
<td>[18.88, 20.58]</td>
<td>[9.64, 10.59]</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>34.1</td>
<td>30.5</td>
<td>16.7</td>
<td>19.8</td>
<td>10.4</td>
</tr>
<tr>
<td></td>
<td>95% CI</td>
<td>[15.71, 34.41]</td>
<td>[16.35, 18.05]</td>
<td>[18.88, 20.58]</td>
<td>[19.8, 20.6]</td>
<td>572.7*</td>
</tr>
<tr>
<td>LPA (% segment length)</td>
<td>Mean (SD)</td>
<td>20.6 (6.10)</td>
<td>28.2 (7.46)</td>
<td>33.0 (9.18)</td>
<td>32.9 (8.86)</td>
<td>33.8 (10.45)</td>
</tr>
<tr>
<td></td>
<td>95% CI</td>
<td>[19.73, 21.66]</td>
<td>[26.92, 29.42]</td>
<td>[31.71, 34.41]</td>
<td>[31.44, 34.24]</td>
<td>[32.14, 35.50]</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>19.5</td>
<td>30.5</td>
<td>32.8</td>
<td>33.0</td>
<td>34.7</td>
</tr>
<tr>
<td></td>
<td>95% CI</td>
<td>[18.88, 34.84]</td>
<td>[31.71, 34.41]</td>
<td>[31.44, 34.24]</td>
<td>[32.14, 35.50]</td>
<td>316.7*</td>
</tr>
<tr>
<td>LPA (% wear time)</td>
<td>Mean (SD)</td>
<td>31.4 (8.63)</td>
<td>32.8 (7.75)</td>
<td>34.0 (9.17)</td>
<td>34.0 (8.98)</td>
<td>34.3 (10.39)</td>
</tr>
<tr>
<td></td>
<td>95% CI</td>
<td>[30.18, 32.87]</td>
<td>[31.57, 34.05]</td>
<td>[32.57, 35.45]</td>
<td>[32.63, 35.34]</td>
<td>[32.68, 35.85]</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>31.3</td>
<td>32.0</td>
<td>33.5</td>
<td>33.6</td>
<td>34.9</td>
</tr>
<tr>
<td></td>
<td>95% CI</td>
<td>[30.96, 31.84]</td>
<td>[32.0, 33.7]</td>
<td>[33.3, 34.2]</td>
<td>[33.4, 34.4]</td>
<td>25.1*</td>
</tr>
<tr>
<td>MVPA (min per day)</td>
<td>Mean (SD)</td>
<td>9.6 (8.05)</td>
<td>8.5 (6.53)</td>
<td>5.9 (5.33)</td>
<td>6.4 (5.44)</td>
<td>3.7 (3.22)</td>
</tr>
<tr>
<td></td>
<td>95% CI</td>
<td>[8.45, 11.11]</td>
<td>[7.62, 9.82]</td>
<td>[5.13, 6.86]</td>
<td>[5.68, 7.38]</td>
<td>[3.26, 4.32]</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>7.7</td>
<td>6.9</td>
<td>4.4</td>
<td>5.0</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td>95% CI</td>
<td>[7.09, 8.34]</td>
<td>[6.36, 7.93]</td>
<td>[3.74, 5.09]</td>
<td>[4.64, 5.89]</td>
<td>488.1*</td>
</tr>
<tr>
<td>MVPA (% segment length)</td>
<td>Mean (SD)</td>
<td>5.5 (4.53)</td>
<td>7.5 (5.58)</td>
<td>11.1 (9.58)</td>
<td>10.7 (9.06)</td>
<td>12.5 (10.74)</td>
</tr>
<tr>
<td></td>
<td>95% CI</td>
<td>[4.92, 6.34]</td>
<td>[6.75, 8.47]</td>
<td>[9.85, 12.99]</td>
<td>[9.49, 12.51]</td>
<td>[10.86, 14.44]</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>4.4</td>
<td>6.0</td>
<td>8.6</td>
<td>8.4</td>
<td>10.2</td>
</tr>
<tr>
<td></td>
<td>95% CI</td>
<td>[3.8, 5.34]</td>
<td>[5.3, 7.3]</td>
<td>[7.8, 9.6]</td>
<td>[7.8, 9.6]</td>
<td>285.6*</td>
</tr>
<tr>
<td>MVPA (% wear time)</td>
<td>Mean (SD)</td>
<td>8.4 (6.67)</td>
<td>8.9 (6.65)</td>
<td>11.5 (9.75)</td>
<td>11.0 (9.29)</td>
<td>12.7 (11.00)</td>
</tr>
<tr>
<td></td>
<td>95% CI</td>
<td>[7.46, 9.65]</td>
<td>[7.96, 10.12]</td>
<td>[10.09, 13.18]</td>
<td>[9.79, 12.80]</td>
<td>[11.09, 14.72]</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>7.0</td>
<td>7.1</td>
<td>9.2</td>
<td>8.7</td>
<td>10.6</td>
</tr>
<tr>
<td></td>
<td>95% CI</td>
<td>[6.34, 7.66]</td>
<td>[6.3, 7.7]</td>
<td>[8.4, 9.9]</td>
<td>[8.3, 9.4]</td>
<td>162.3*</td>
</tr>
</tbody>
</table>

Note. LPA = light physical activity; MVPA = moderate-to-vigorous physical activity; 95% CI = bias-corrected and accelerated bootstrap 95% confidence interval. Mean accelerometer wear (% of segment length): Definition 1, 66.2%; Definition 2, 85.5%; Definition 3, 96.8%; Definition 4, 96.6%; Definition 5, 98.2%.

* Significant difference between segments (p < .001) determined by Friedman test.
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

Figure 2 — Distribution of PA data by segment definition. Outside values (outliers) are not plotted. PA = physical activity.
in misclassification (i.e., classifying sleep time as sedentary or nonwear time)—a limitation observed in a study that assigned generalized 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-hr hip or wrist accelerometer wear (see Smith et al., 2020; van Hees et al., 2018, e.g.). With these developments, 24-hr wear protocols should be considered as an alternate approach to waking-hour 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 generalized time period will lead to the inclusion of noncommuting PA behaviors (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, 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 activity 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 recognized. 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 contextualize active before-school behaviors.

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 (6:00 a.m. start), participants needed to attach the device no later than 7:15 a.m.–7:35 a.m., and wear it continuously until school start time. While the average school-day wake time of Australian adolescents falls earlier than 7:15 a.m. (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 cutoff, delays in device attachment may result in exclusion from analyses, which may be overcome by implementing a 24-hr device wear protocol (Tudor-Locke et al., 2015).

Some studies applied before-school segment definitions encompassing 60 min or less 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 nonwear 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 standardized 1-hr 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 analyzing time immediately prior to school, such as to capture travel behaviors, 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 are impacted by total wear time. While these results show the potential to exclude 25 min 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 toward LPA increases (Contardo Ayala et al., 2022; Grästén et al., 2021), studies examining this behavior 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, and sunrise time) preclude widespread standardization 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

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**MEASURING BEFORE-SCHOOL PHYSICAL ACTIVITY**

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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-hr wear protocol and applying a wake-time algorithm is one possible approach (Tudor-Locke et al., 2015). Individualized segment start times may then be established, to overcome the issue of misclassifying sleep as nonwear, or, alternatively, excluding waking time.

The combined methods of a systematic search and review with analyses of before-school PA data are 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 minimize 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 noncompliance, 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. In addition, while our aim was not to examine before-school PA levels, nor to generalize 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, nonrepresentative sample. Reported PA levels should, therefore, be interpreted with caution.

Conclusions

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.

Acknowledgments

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References


