A systematic review in device-measured physical activity during active commuting to/from school: practical considerations to assess when, where, and how much it occurs

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Abstract

Active commuting to/from school (ACS) is an efficient manner to increase daily physical activity (PA) levels. However, there seems to be no consensus on the best methodology to accurately assess ACS-PA. Therefore, this systematic review aimed (1) to compile and review the methodologies used in device-measured ACS-PA in young people, including the definition of the times (i.e., start/end times) and the locations (i.e., home/school) of the trips (i.e., when and where), and how to quantify the ACS-PA mode, intensity, and volume with devices (e.g., accelerometers, pedometers) , (2) to analyse the strengths and limitations of these methodologies, and (3) to propose practical recommendations for ACS-PA measurement. A systematic search was carried out up to 2021 in five different databases. The systematic search yielded 6,274 references, of which 27 papers met the inclusion criteria (See PMC7459731). Methodologies used to assess ACS-PA were heterogenous, especially on how to determine the times when ACS takes place. The start/end times of the trips were mainly identified using predefined time intervals, even though GPS-based detection were also used in some studies. Regarding how to quantify the ACS-PA, the main mode of ACS assessed was walking and the most used device was the accelerometer to quantify the PA intensity. This systematic review provides the strengths and limitations of each method, proposes solutions to appropriately measure ACS-PA, and includes a decision tree for helping researchers' decision-making.

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Keywords: device-measured physical activity; GPS; active transport; school; health promotion; youth

1. Introduction

Engaging in regular physical activity (PA) provides many physical, social, and psychological benefits (Poitras et al., 2016). According to World Health Organization recommendations, youths aged 5-17 years old need to accumulate at least 60 minutes/day of moderate-to-vigorous physical activity (MVPA) on average to achieve greater benefits (Chaput et al., 2020). However, the majority of the young people do not meet these recommendations (Guthold et al., 2020). Thus, in line with the Global Action Plan 2018-2030 (*Global Action Plan on Physical Activity 2018-2030: More Active People for a Healthier World*, 2019), effective strategies to promote PA in early life are necessary for the prevention of future health problems in adulthood (Katzmarzyk et al., 2021; Messing et al., 2019). Adolescents may engage in regular PA in many ways, such as recreational activities, organized sports, or active transportation (i.e., walking or cycling), all of which may have different health benefits (Salmon & Timperio, 2007). Active commuting is of particular interest given its low economic cost, its regularity, and the several health and environmental benefits associated with it (Larouche et al., 2014; Schoeppe et al., 2013).

Specifically, active commuting to/from school (ACS), by walking or cycling mainly, has been recognized as a promising strategy to increase daily PA levels (Kek et al., 2019; Larouche et al., 2014; Martin et al., 2016), school-day PA (Kek et al., 2019; Sirard et al., 2005), and before- and after-school PA among young people (Kek et al., 2019; Mendoza et al., 2011). In addition, ACS also provides other health (Larouche et al., 2014; Waygood et al., 2017), economic (Gössling et al., 2019), and environmental benefits (Giles-Corti et al., 2010). Nevertheless, despite the well-known benefits of ACS on increasing young people's daily PA levels, there is no consensus on the measurement of active commuting-related PA (hereinafter referred to as ACS-PA) using device-measured PA (Martin et al., 2016). This lack of consensus may limit the quantification of the amount of ACS-PA. For example, non-differentiating commuting modes (e.g., walking or cycling) may lead to lack of sensitivity to define the specific benefits of each mode (Larouche et al., 2014); or inaccuracies in the definition of the time of the trips may lead to including activities outside the time interval of interest (e.g., after-school activities, activities before leaving home, or high levels of sedentary time due to the proximity of home to school) (Denstel et al., 2015; Owen et al., 2012). For that reason, ACS-PA is usually measured in two phases: (i) the identification of the times (i.e., start/end times) and locations (home/school) of the trips, and (ii) the quantification of the PA that has occurred in the times and between the locations identified in the first phase.

Regarding the identification of the times of the trips, usual approaches include the use of geolocation devices, self-reported trip diaries, or predefined time intervals (e.g., 30 minutes prior and after school hours). Global Positioning System (GPS) is considered the most accurate approach as they provide objective continuous trip information (Duncan et al., 2009; Jankowska et al., 2015). However, there are limitations associated with the use of GPS such as battery life, potential loss of satellite signaling, among others (Duncan et al., 2009; Edgecomb & Norton, 2006). Self-reported trip times might overestimate or underestimate the start/end time by more than 10 minutes (Stopher & Greaves, 2010), and predefined time intervals commit the big assumption that the trip time is constant across participants (Kelso et al., 2021). On the other hand, the identification of the locations is not taken into account in those studies that did not use GPS since they considered only a determined time interval in which the commuting to/from school is supposed to take place. Whereas for the studies that used GPS, it is necessary to locate the start or end in order to be able to define the commuting to/from school correctly at a spatial level. Thus, a correct definition of the trips' times and locations is necessary to avoid spurious findings that do not match the research question and the results obtained.

Regarding how to quantify ACS-PA , usual metrics include the activity mode or type (e.g., walking, cycling), the intensity of the activity performed (e.g., time in MVPA), or the number of steps during the trip, although these metrics might be affected by the approach used to quantify the PA. Usual approaches to quantify PA include self-reported information (e.g., activity mode, time spent) and device-based estimates (e.g., accelerometer, pedometers, or heart rate sensors). Each has certain advantages and limitations, as well as some considerations for the appropriate use and interpretation of their data, but this information has never been discussed in the context of ACS-PA.

Considering the large number of methodologies used to measure ACS-PA, a review of all of them is indispensable to help researchers and practitioners in this field to make better decisions in their studies. Therefore, the aims of this systematic review were: (1) to compile and review the methodologies used in device-measured ACS-PA in young people, including the definition of the times (i.e., start/end times) and the locations (i.e., home/school) of the trips (i.e., when and where), and how to quantify the ACS-PA mode, intensity, and volume with devices (e.g., accelerometers, pedometers) , (2) to analyse the strengths and limitations of these methodologies, and (3) to propose practical recommendations for ACS-PA measurement.

2. Methods

The detailed methodology of the current systematic review is available for consultation elsewhere (Campos-Garzón et al., 2020) and was registered in the PROSPERO International Prospective Register of Systematic Reviews (CRD42020162004). Moreover, the checklist "Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement" has been used for the development of the systematic review (Page et al., 2021).

2.1. Inclusion criteria

This systematic review has included cross-sectional, longitudinal, and intervention studies (i.e., randomized trials and non-randomized studies) assessing ACS-PA with device-measured PA. It is also important to highlight that in studies with several measurement times (e.g., longitudinal, intervention studies, etc.), the information and data from the first measurement time (i.e., baseline) were considered. The population of the studies included were children (from 6 to 12 years old) and/or adolescents (from 13 to 18 years old) who actively commute to/from school under free-living conditions. Furthermore, ACS mode (e.g., walking, cycling), intensity (e.g., light, moderate, vigorous), or volume (e.g., steps, activity counts, calories) had to be reported. Only studies with the title and abstract written in English or Spanish and peer-reviewed studies from the scientific literature were included.

2.2. Search strategy

The search strategy was based on the recommendations of (Gusenbauer & Haddaway, 2019) and previous systematic reviews on the topic (Aranda-Balboa et al., 2020; Villa-González et al., 2018). As a result, a series of word combinations were performed according to the PICO (population, intervention, comparisons, and outcomes) strategy (Eriksen & Frandsen, 2018). Finally, the systematic search was conducted in five different databases (Pubmed, Web of Science, SPORTdiscuss, Cochrane Library, and National Transportation Library) up to 8th of October of 2021 (See and the protocol of the current systematic review for detailed information on the systematic searches performed) (Campos-Garzón et al., 2020).

2.3. Study selection

EndNote citation management software was used to record the search results and remove duplicate studies. Study selection was carried out in three steeps (Gunnell et al., 2020): (1) titles and abstracts were screened, following the inclusion criteria, by P.C.-G. paired with other authors (R.G.S.-A., J.S-S., Y.B.-R., and P.Ch.); (2) the full-text articles were screened in the same pairs as in the first step; (3) the references of the studies included were also analyzed by P.C.-G. and R.G.S.-A., in order to identify other potential articles that could be ignored in the search strategy. The average agreement among the authors was 78% in the first step and 83% in the second step. In addition, the authors obtained 100% agreement after resolving discrepancies through discussion.

2.4. Data extraction

Data from the studies included were carefully identified and selected by P.C.-G. and R.G.S.-A. In addition, J.S.-S., Y.B.-R., and P.Ch. also performed data extraction of 10% of the studies included, following the (Nevis et al., 2015) recommendation. Discrepancies were solved by discussion of the authors involved. Furthermore, when relevant information was needed, the authors of the studies included were contacted by e-mail. The following descriptive categories were extracted from each of the identified studies: (1) Characteristics of the studies: authors (years) and country, study design, and participant´s age group; (2) Identification of the times and locations of the trips: synthesis of ACS-PA methodology (i.e., what kind of methodology was used to determine the start/end times), time definition (e.g., if the studies decided to use a predefined time interval, the duration of this time interval for before and/or after school was indicated; if GPS was used, it would be considered "not applicable"), and locations definition; (3) How to quantify ACS-PA: mode of ACS assessment (i.e., tool used for the assessment of the mode of ACS), mode of ACS categorization (i.e., classification of the mode of ACS assessed [e.g., walking, cycling]), device-measured PA used, device placement, and other measurement device (if pertinent).

2.5. Data synthesis

The prior intention was to divide the results of the studies included according to the mode of ACS (i.e., walking and cycling) (Campos-Garzón et al., 2020). As only four studies reported cycling data (Cooper et al., 2012; Pizarro et al., 2016; Stewart et al., 2017a; Tarp et al., 2015) (see Table 2), it was decided not to split the synthesis of results by mode of ACS (i.e., walking and cycling). Moreover, a summary of the measurement tools used in the identification of the times and locations of the trips (i.e., where and when) and how to quantify the ACS-PA (i.e., how much) are shown in Table 1. Table 2 shows a more detailed information of the ACS-PA methodologies used by the studies included. It is important to note that the age of the participants shown in Table 2 refers to the age of the active commuters reported in the study. In addition, the presence of self-reported tools in the Table 2 only refers to how some studies determined the mode of commuting to and from school or defined the times and locations of the trip, but the ACS-related intensity of these studies was determined by device-measured PA. When the required information on any item was not reported, because it was not the objective of the study, the item was rated as "not applicable". In case of any data were not reported or provided unclear information, the item was rated as "not clear".

3. Results

A total of 6,274 original studies were obtained from the systematic search. After discarding 1,302 duplicate studies, 4,972 original articles were screened by title and abstract. Of these, 191 articles were reviewed in full text and, after applying the inclusion criteria, a final number of 27 studies were included in the current systematic review: two intervention studies, two longitudinal studies, and 23 cross-sectional studies (see Figure. 1 for full search details).

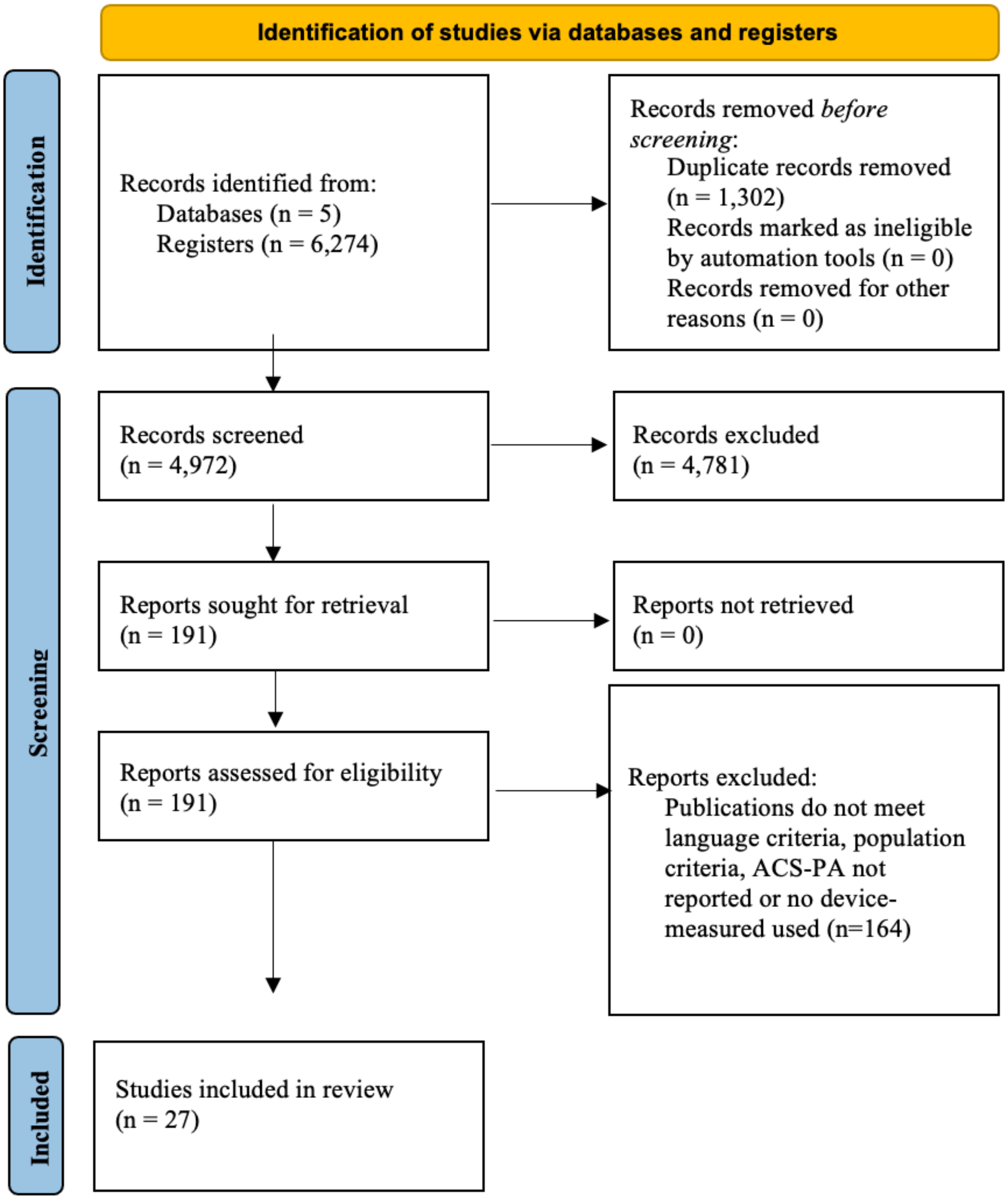

Figure. 1 Flow diagram of the literature search and study selection process

3.2. Identification of the times and locations of the trips

The times of the trips to assess ACS-PA were determined differently in most studies. In the home-school trips, the vast majority of the studies included used a predefined time interval of 60 minutes, except for three studies that reported neither the start time nor the end time (e.g., awakening, school start time-bell) (Loucaides & Jago, 2008; Saksvig et al., 2007, 2012), while other studies used 180 minutes (Mendoza et al., 2011), 44 minutes (Sirard et al., 2008), or 30 minutes as predefined time interval when youths actively commute to school (Chillon et al., 2017). In addition, six studies used GPS to determine the times and the locations of the school trips (Lee & Li, 2014; Pizarro et al., 2016; Stewart et al., 2017a; Tarp et al., 2015; Villa-Gonzalez et al., 2019; Voss et al., 2015), two studies used GPS and a predefined time interval (Remmers et al., 2020; Voss et al., 2014), and one of the studies used the algorithms of Barreira et al. (2015) to determine these times (Denstel et al., 2015). Moreover, in the school-home trips, five studies used a predefined time interval of 60 minutes (Ford et al., 2007; Frazer et al., 2015; Gale et al., 2021; Kek et al., 2019; Pabayo et al., 2012), two studies reported neither the start time nor the end time (e.g., school end bell-time) (Saksvig et al., 2007, 2012), while other studies used 120 minutes (Owen et al., 2012), 90 minutes (Mendoza et al., 2011), or 30 to assess ACS (Chillon et al., 2017), and one of the studies used GPS and a predefined time interval (Voss et al., 2014). As above, four of the studies used GPS to determine the times and locations of the trips from school to home (Lee & Li, 2014; Pizarro et al., 2016; Stewart et al., 2017a; Tarp et al., 2015), and one study used the algorithms of Barreira et al. (2015) to determine the times (Denstel et al., 2015).

3.3. How to quantify ACS-PA: mode, intensity, and volume

Regarding the assessment of the mode of commuting to/from school, only two studies assessed the mode of commuting to school using GPS (Villa-Gonzalez et al., 2019; Voss et al., 2015), one combined self-report tools and GPS (Remmers et al., 2020), and the rest of the studies used self-report tools (Cooper et al., 2003, 2005, 2010, 2012; Denstel et al., 2015; Ginja et al., 2017; Loucaides & Jago, 2008; Martinez-Martinez et al., 2019; Sirard et al., 2008; Voss et al., 2015). On the other hand, three studies used GPS to assess both trips' directions (Pizarro et al., 2016; Stewart et al., 2017a; Tarp et al., 2015), two combined self-report tools and GPS (Lee & Li, 2014; Voss et al., 2014), and the rest only used self-report tools. The most common mode of ACS was walking, except for four studies that examined walking and cycling separately (Cooper et al., 2012; Pizarro et al., 2016; Stewart et al., 2017a; Tarp et al., 2015), and five studies that did not report the type of ACS (Gale et al., 2021; Ginja et al., 2017; Kek et al., 2019; Mendoza et al., 2011; Remmers et al., 2020). Regarding ACS-PA measured with devices-measured PA, the accelerometer was the most used device to assess ACS-PA intensity, only two studies used pedometers (Loucaides & Jago, 2008; Pabayo et al., 2012), and one combined accelerometer and heart rate monitor (Tarp et al., 2015). All the studies used ActiGraph models (e.g., ActiGraph 7164, ActiGraph GT1M, Actigraph GT3X, or ActiGraph

GT3X+), and for pedometer brands, (Loucaides & Jago, 2008) used Yamax and (Pabayo et al., 2012) Omron.

In terms of device-measured PA placement, almost all the studies placed the device-measured PA on the hip or waist and one on the lower back (Chillon et al., 2017) and three studies did not report the device-measured PA placement (Martinez-Martinez et al., 2019; Pabayo et al., 2012; Saksvig et al., 2012). However, all of them were placed on the hip because of the cut-off points used (Martinez-Martinez et al., 2019), the brand of pedometer used (Pabayo et al., 2012), and the brand of pedometer and the cut-off points used (Loucaides & Jago, 2008).

Table 1. Most-frequently used measurement tools to identify the times and locations of the trips and how to quantify the ACS-PA.

Phases for measuring ACS-PA	**Variables of interest**	**Measurement tools (n)**
Identification of the times and locations of the trips (when and where)	Distance from/to school Duration of the trips Home and school locations[d]	GPS (8)[e] Predefined time intervals (20)[e] Algortihm of Barreira et al. (2015) (1)
How to quantify ACS-PA (how much)	PA mode[a] PA intensity[b] PA duration[c]	Accelerometer (25) Pedometer (2) Self-reported (22) GPS (4)

[a]e.g., walking, cycling; [b]e.g., light, moderate, vigorous, steps per minute; [c]i.e., time spent in certain PA intensities and/or modes; [d]e.g., home and school locations were only determined by GPS; [e]e.g., studies using self-report and GPS were included in both categories.

ACS: active commuting to/from school; PA: physical activity; n: number of studies using this measurement tool; GPS: global positioning system

Table 2 Characteristics of the studies included to assess ACS-PA

Characteristics of the studies			**Identification of the times and locations of the trips**			**How to quantify the ACS-PA**				
Authors (year), country	**Study design**	**Participant´s age group (sample, % girls; average and/or range age)****	**Synthesis of ACS-PA methodology**	**Time interval (1) Before school (2) After school**	**Locations identified**	**Mode of ACS assessment (1) To school (2) From school**	**Mode of ACS categorization**	**Device-measured PA (brand)**	**Device placement**	**Other measurement device**
Cooper et al. (2002), United Kingdom	Cross-sectional	Children (74, 50% girls; 10.4 years)	Use of time interval before school	(1) 60 minutes (2) Not applicable	Not applicable	(1) Self-reported (2) Not applicable	Walking	Accelerometer (ActiGraph)	Right hip	Not applicable
Cooper et al. (2003), Denmark	Cross-sectional	Children (50, 82% girls; 9.7 years)	Use of time interval before school	(1) 60 minutes (2) Not applicable	Not applicable	(1) Self-reported (2) Not applicable	Walking	Accelerometer (ActiGraph)	Right hip	Not applicable
Ford et al. (2007), United Kingdom	Cross-sectional	Children (108, 45.4% girls; 8.3 years)	Use of time interval before school	(1) 60 minutes (2) 60 minutes	Not applicable	(1) Self-reported (2) Self-reported	Walking	Accelerometer (ActiGraph)	Right hip	Not applicable

Characteristics of the studies			Identification of the times and locations of the trips			How to quantify the ACS-PA				
Authors (year), country	**Study design**	**Participant´s age group (sample, % girls; average and/or range age)****	**Synthesis of ACS-PA methodology**	**Time interval (1) Before school (2) After school**	**Locations identified**	**Mode of ACS assessment (1) To school (2) From school**	**Mode of ACS categorization**	**Device-measured PA (brand)**	**Device placement**	**Other measurement device**
Saksvig et al. (2007), United States	Cross-sectional	Children (112, 100% girls; 12 years)	Use of time interval before school	(1) 6:00 am-school start bell time (2) School end bell time-5:00 pm	Not applicable	(1) Self-reported (2) Self-reported	Walking	Accelerometer (ActiGraph)	Waist	Not applicable
Loucaides & Jago (2008), Cyprus	Cross-sectional	Children (65; 11.1 years)	Use of time interval before school	(1) Awakening-7:45 am (2) Not applicable	Not applicable	(1) Self-reported (2) Not applicable	Walking	Pedometer (Yamax)	Waist	Not applicable
Sirard et al. (2008)*, United States	Randomized controlled trial	Children (5, 60% girls; 9.7 years)	Use of time interval before school	(1) 44 minutes (2) Not applicable	Not applicable	(1) Self-reported (2) Not applicable	Walking	Accelerometer (ActiGraph)	Waist	Not applicable

Characteristics of the studies			**Identification of the times and locations of the trips**			**How to quantify the ACS-PA**				
Authors (year), country	**Study design**	**Participant´s age group (sample, % girls; average and/or range age)****	**Synthesis of ACS-PA methodology**	**Time interval (1) Before school (2) After school**	**Locations identified**	**Mode of ACS assessment (1) To school (2) From school**	**Mode of ACS categorization**	**Device-measured PA (brand)**	**Device placement**	**Other measurement device**
Cooper et al. (2010), United Kingdom	Cross-sectional	Children (135, 46.7% girls; 11.3 years)	Use of time interval before school	(1) 60 minutes (2) Not applicable	Not applicable	(1) Self-reported (2) Not applicable	Walking	Accelerometer (ActiGraph)	Waist	Not applicable
Mendoza et al. (2011), United States	Cross-sectional	Adolescents (789, 48.6% girls; 14.4 years)	Use of time interval before and after school	(1) 180 minutes (2) Not applicable	Not applicable	(1) Self-reported (2) Self-reported	Not clear	Accelerometer (ActiGraph)	Right hip	Not applicable
Cooper et al. (2012)*, United Kingdom	Longitudinal	Children (565, 55.2% girls; 11.0 years)	Use of time interval before school	(1) 60 minutes (2) Not applicable	Not applicable	(1) Self-reported (2) Not applicable	Walking Cycling	Accelerometer (ActiGraph)	Waist	Not applicable

Characteristics of the studies			Identification of the times and locations of the trips			How to quantify the ACS-PA				
Authors (year), country	**Study design**	**Participant´s age group (sample, % girls; average and/or range age)****	**Synthesis of ACS-PA methodology**	**Time interval (1) Before school (2) After school**	**Locations identified**	**Mode of ACS assessment (1) To school (2) From school**	**Mode of ACS categorization**	**Device-measured PA (brand)**	**Device placement**	**Other measurement device**
Owen et al. (2012), United Kingdom	Cross-sectional	Children (1,393, 53.2% girls; aged 9-11 years)	Use of time interval before and after school	(1) 60 minutes (2) 120 minutes	Not applicable	(1) Self-reported (2) Self-reported	Walking	Accelerometer (ActiGraph)	Left hip	Not applicable
Pabayo et al. (2012), Canada	Cross-sectional	Children (688, 53.8% girls; 10.9 years)	Use of time interval before and after school	(1) 60 minutes (2) 60 minutes	Not applicable	(1) Self-reported (2) Self-reported	Walking	Pedometer (Omron)	Not reported	Not applicable
Saksvig et al. (2012), United States	Cross-sectional	Children (944, 100% girls)	Use of 2 protocols: (1) Use of time interval before and after school, (2) Use of two EE (i.e., 3 METS or 4.6 METS) to determine the walking speed	(1) 6:00 am- start bell time (2) End bell time- 5:00 pm	Not applicable	(1) Self-reported (2) Self-reported	Walking	Accelerometer (ActiGraph)	Not reported	Not applicable

Characteristics of the studies			Identification of the times and locations of the trips			How to quantify the ACS-PA				
Authors (year), country	**Study design**	**Participant´s age group (sample, % girls; average and/or range age)****	**Synthesis of ACS-PA methodology**	**Time interval (1) Before school (2) After school**	**Locations identified**	**Mode of ACS assessment (1) To school (2) From school**	**Mode of ACS categorization**	**Device-measured PA (brand)**	**Device placement**	**Other measurement device**
Lee & Li (2014), United States	Cross-sectional	Children (112, 50.8% girls; aged 7-12 years)	Use of a GPS device	(1) Not applicable (2) Not applicable	By GPS	(1) Self-reported and by GPS (2) Self-reported and by GPS	Walking	Accelerometer (ActiGraph)	Right hip	GPS (Garming Forerunner 2005)
Voss et al. (2014), Canada	Cross-sectional	Children (49, 37% girls; 13.3 years)	Use of 2 protocols: (1) Use of time interval before and after school, (2) Use of a GPS device	(1) 60 minutes (2) 60 minutes	By GPS	(1) Self-reported and by GPS (2) Self-reported and by GPS	Walking	Accelerometer (ActiGraph)	Right hip	GPS (Qstarz BT-Q1000XT) Epoch: 1s
Denstel et al. (2015), 12 countries	Cross-sectional	Children (2,639, 41.8% girls;	Use of time interval before school calculated	(1) Barreira et al. algorithm	Not applicable	(1) Self-reported (2) Not applicable	Walking	Accelerometer (ActiGraph)	Waist	Not applicable

Characteristics of the studies			Identification of the times and locations of the trips			How to quantify the ACS-PA				
Authors (year), country	**Study design**	**Participant´s age group (sample, % girls; average and/or range age)****	**Synthesis of ACS-PA methodology**	**Time interval (1) Before school (2) After school**	**Locations identified**	**Mode of ACS assessment (1) To school (2) From school**	**Mode of ACS categorization**	**Device-measured PA (brand)**	**Device placement**	**Other measurement device**
		aged 9-11 years)	by Barreira et al. algorithm	(2) Barreira et al.algortihm						
Frazer et al. (2015), Canada	Cross-sectional	Adolescents (60, 56.57% girls; 15.05 years)	Use of time interval before and after school	(1) Hour before school (2) Hour after school	Not applicable	(1) Self-reported (2) Self-reported	Walking	Accelerometer (ActiGraph)	Right hip	Not applicable
Tarp et al. (2015), Denmark	Cross-sectional	Children and adolescents (20, 35% girls; 12.2 years/aged 11-14 years)	Use of a GPS device	(1) Not applicable (2) Not applicable	By GPS	(1) By GPS (2) By GPS	Walking Cycling	Accelerometer (ActiGraph) Heart rate monitor (Polar)	Right hip	GPS (Qstarz-BT-Q1300S) Epoch: 5s

Characteristics of the studies			Identification of the times and locations of the trips			How to quantify the ACS-PA				
Authors (year), country	**Study design**	**Participant´s age group (sample, % girls; average and/or range age)****	**Synthesis of ACS-PA methodology**	**Time interval (1) Before school (2) After school**	**Locations identified**	**Mode of ACS assessment (1) To school (2) From school**	**Mode of ACS categorization**	**Device-measured PA (brand)**	**Device placement**	**Other measurement device**
Voss et al. (2015), Canada	Cross-sectional	Adolescents (42, 36% girls; 13.3 years)	Use of a GPS device	(1) Not applicable (2) Not applicable	By GPS	(1) By GPS (2) Not applicable	Walking	Accelerometer (ActiGraph)	Right hip	GPS (Qstarz-BTQ1000XT) Epoch: 1s
Pizarro et al. (2016), Portugal	Cross-sectional	Adolescents (155, 55% girls; 15,9 years)	Use of a GPS device	(1) Not applicable (2) Not applicable	By GPS	(1) By GPS (2) By GPS	Walking Cycling	Accelerometer (ActiGraph)	Waist	GPS (Qstarz-BTQ1000XT) Epoch: 15s
Chillón et al. (2017), Spain	Cross-sectional	Children (192, 47% girls; 10.2 years) Adolescents (197, 50% girls; 14.7 years)	Use of time interval before and after school	(1) 30 minutes (2) 30 minutes	Not applicable	(1) Self-reported (2) Self-reported	Walking	Accelerometer (ActiGraph)	Lower back	Not applicable

Characteristics of the studies			Identification of the times and locations of the trips			How to quantify the ACS-PA				
Authors (year), country	**Study design**	**Participant´s age group (sample, % girls; average and/or range age)****	**Synthesis of ACS-PA methodology**	**Time interval (1) Before school (2) After school**	**Locations identified**	**Mode of ACS assessment (1) To school (2) From school**	**Mode of ACS categorization**	**Device-measured PA (brand)**	**Device placement**	**Other measurement device**
Ginja et al. (2017)*, United Kingdom	Cluster randomized trial	Children (15, 46.7% girls; 9 years)	Use of 2 protocols: (1) Use of time interval before school, (2) Use of time interval reported by parents	(1) 59 minutes (2) Not applicable	Not applicable	(1) Self-reported (2) Not applicable	Not clear	Accelerometer (ActiGraph)	Waist	Not applicable
Stewart et al. (2017), New Zeland	Cross-sectional	Adolescents (186, 40.8% girls; 14.7 years)	Use of a GPS device	(1) Not applicable (2) Not applicable	By GPS	(1) By GPS (2) By GPS	Walking Cycling	Accelerometer (ActiGraph)	Right hip	GPS (Qstarz-BTQ1000XT) Epoch: 5s

Characteristics of the studies			Identification of the times and locations of the trips			How to quantify the ACS-PA				
Authors (year), country	**Study design**	**Participant´s age group (sample, % girls; average and/or range age)****	**Synthesis of ACS-PA methodology**	**Time interval (1) Before school (2) After school**	**Locations identified**	**Mode of ACS assessment (1) To school (2) From school**	**Mode of ACS categorization**	**Device-measured PA (brand)**	**Device placement**	**Other measurement device**
Kek et al. (2019), New Zeland	Cross-sectional	Adolescents (73, 45% girls; 14.7 years)	Use of time interval before and after school	(1) 60 minutes (2) 60 minutes	Not applicable	(1) Self-reported (2) Self-reported	Not clear	Accelerometer (ActiGraph)	Right hip	Not applicable
Martínez-Martínez et al. (2019), Spain	Cross-sectional	Children (172; 9 years)	Use of time interval before school	(1) 60 minutes (2) Not applicable	Not applicable	(1) Self-reported (2) Not applicable	Walking	Accelerometer (ActiGraph)	Not reported	Not applicable
Villa-González et al. (2019), Spain	Cross-sectional	Adolescents (18, 66.7% girls; 15 years)	Use of a GPS device	(1) Not applicable (2) Not applicable	By GPS	(1) By GPS (2) Not applicable	Walking	Accelerometer (ActiGraph)	Right hip	GPS (Qstarz-BTQ1000XT) Epoch: 5s
Remmers et al. (2020)*, Netherland	Longitudinal	Children (175, 49.14% girls; 12.1 years)	Use of a GPS device and time interval	(1) 6:00 am- start school time (2) Not applicable	By GPS	(1) Self-reported and by GPS (2) Not applicable	Not clear	Accelerometer (ActiGraph)	Right hip	GPS (Qstarz-BTQ1000XT) Epoch: 1s

Characteristics of the studies			Identification of the times and locations of the trips			How to quantify the ACS-PA				
Authors (year), country	**Study design**	**Participant´s age group (sample, % girls; average and/or range age)****	**Synthesis of ACS-PA methodology**	**Time interval (1) Before school (2) After school**	**Locations identified**	**Mode of ACS assessment (1) To school (2) From school**	**Mode of ACS categorization**	**Device-measured PA (brand)**	**Device placement**	**Other measurement device**
Gale et al. (2021), New Zealand	Cross-sectional	Adolescents (26, 100% girls; 16.7 years)	Use of time interval before and after school.	(1) 60 minutes (2) 60 minutes	Not applicable	(1) Self-reported (2) Self-reported	Not clear	Accelerometer (ActiGraph)	Right hip	Not applicable

*Only the information and data of the first measurement time (i.e., baseline) was considered; **Only the information of participants who ACS was considered.
ACS-PA: active commuting to/from school related PA; ACS: active commuting to/from school; PA: physical activity; EE: energy expenditure: METs: metabolic equivalence of task; GPS: global positioning system
Studies were ordered chronologically by year.

4. Discussion

The aims of this systematic review were: (1) to compile and review the methodologies used in device-measured ACS-PA in young people, including the definition of the times (i.e., start/end times) and the locations (i.e., home/school) of the trips (i.e., when and where), and how to quantify the ACS-PA mode, intensity, and volume with devices (e.g., accelerometers, pedometers), (2) to analyse the strengths and limitations of these methodologies, and (3) to propose practical recommendations for ACS-PA measurement. The three main findings are as follows: (1) Methodologies used to assess ACS-PA were heterogenous among the studies included, especially on how to determine the times of the trips when ACS takes place; (2) the times of the trips were mainly identified using predefined time intervals, while self-reports and GPS-based detection were also used in some studies; (3) regarding the quantification of the ACS-PA, the main mode of ACS assessed among studies was walking or was reported as ACS without specifying whether walking or cycling to/from school. Moreover, accelerometer was the most used device-measured PA, followed by the pedometer to quantify the PA intensity during ACS. Following these findings, the authors propose that to measure ACS-PA it would be ideal: (a) to identify the times and locations of the school trips by using GPS since it is the device that allows knowing the geolocation of the participant individually. This means being able to know at what moment (start/end times) each participant leaves home (home location) and arrives at school (school location), and vice versa; (b) for the quantification of ACS-PA, the accelerometer should be used because of the amount of information it provides: intensity, possibility to time stamp for GPS linkage, or duration (volume of PA). It can even recognize the type of activity performed (e.g., walking or cycling) using the latest trends in data processing. In the case of difficulties in using GPS (e.g., excessive satellite signal error, economic issues), the authors propose to use self-reported measures to identify the times of the trips, so that this period is individualized for participants. Similarly, if accelerometers are not available, pedometers should be considered for PA quantification. Nevertheless, the need for a standardized protocol for measuring the specific time-context when ACS-PA takes place and further methodological studies will facilitate the understanding, the interpretation, and comparison of results across studies.

4.1. Identification of the times and locations of the trips

The assessment on ACS-PA primarily relies on the identification of the times and locations of the trips (Katapally et al., 2020), including both the time frame when ACS occurs (i.e., starting/ending times) and, if the GPS is used, the space where ACS starts (e.g., home location) and ends (e.g., school location) (for a further review see; https://thets.github.io/palmsplusr/articles/article-1-getting-started.html).

Three different strategies have been mostly used in research literature to identify the times of the trips in which ACS-PA occurs: predefined time intervals, self-reported, and GPS-determined. Most of the studies included assessed ACS-PA by predefining time intervals (e.g., 30 minutes before and after school). The use of a common time interval precludes obtaining detailed information at the individual level (Kelso et al., 2021), because the same time interval is set for all participants, whereas if youth report their times of the trips, these are individualized. The self-reporting times must be taken cautiously because can be up to a variation of almost 30% between self-reported and GPS-measured data (Bekö et al., 2015). Self-reported measures can determine the times of the trips, but they are characterized by their low sensitivity and accuracy in recording a behaviour or the context in which this behaviour takes place (Jankowska et al., 2015). Thus, studies comparing self-reported tools and geolocation devices are needed to check whether the questionnaires show a good ACS start/end times estimation. Therefore, it is essential to establish how the identification of the times of the trips will be assessed, since once defined, it will be possible to understand the ACS-PA among the population (Jaeschke et al., 2017; Katapally et al., 2020; Vanky et al., 2017).

On the other hand, in our systematic review, only eight studies used GPS to determine the times of the trips. To date, the most widely used measurement device in research literature to contextualize the timing of ACS is GPS (Klinker et al., 2015; Jankowska et al., 2015; Krenn et al., 2011). The latitude, longitude, and time data provided by GPS allow the location of the participant while performing specific activities at all times (Jankowska et al., 2015; Kerr et al., 2011). The traditional limitations of GPS (e.g., distance underestimation, lack of signal precision due to infrastructure) (Duncan et al., 2009; Edgecomb & Norton, 2006) have been overcome with modern GPS devices (Jankowska et al., 2015; Krenn et al., 2011). However, regarding these eight studies that used GPS in our systematic review, they reported limitations that may influence the identification of the start/end of the trips, such as loss of satellite signal, high dropout given the low compliance rate with the study protocol, short battery life, and the lack of a protocol for interpreting GPS data. To overcome all these issues, it will be essential to conduct a pilot test of GPS functioning in the area prior to implementing this tool to any project. For example, Schipperijn et al. (2014) found that the accuracy of the QTARZ Q100XT GPS was adequate for determining the time frame, but highlighted that, depending on the environment, the signal could negatively influence its accuracy. In addition, in case of signal error, the use of self-reported tools (e.g., online mapping) could be a complementary tool to determine the times of the trips (Stewart et al., 2017b). Regarding battery life there are three possible solutions: (1) to increase the battery life of the GPS devices for at least one week of autonomous recording; (2) the one used by Villa-Gonzalez et al. (2019) , in which a researcher charged the GPS device during school mornings and the dropout rate was only 10%; (3) to program the GPS to record at specific time periods (e.g., from 7:00 to 10:00 am, and from 2:00 to 5:00 pm) to optimize battery life.

Regarding the identification of the trip locations, studies using GPS indicated that to determine the times of the trips, it was also needed to geolocate the home, school, and the trip followed by the youth. To date, there is no standard procedure to geolocate the home, school, or trip. For example, Pizarro et al. (2016) and Villa-Gonzalez et al. (2019) defined the home with a buffer of 25m (i.e., creating an area with a radius of 25m and the center of the circumference are the coordinates of the youth's house), and the school was geolocated in its entire area. The start of the trip was established as greater than or equal to 100m travelled from the origin (i.e., school or home) with an average speed of 1.5km/h or more, and the end of the trip was defined as pauses longer than three minutes. Similarly, Stewart et al. (2017a) defined home by a 50-metre buffer. The school was also geolocated, but in this case, the start of trip was set as at minimum of 2 minutes of movement in which a minimum distance of 100m or more will be reached, with the end of the trip being a pause longer than three minutes. However, some limitations may be associated with pauses longer than three minutes such as waiting at a bus or metro stop. To overcome this problem, Stewart et al. (2017a) introduce the concept of multimodal trip defined as new trips following the last identified trip with the following characteristics: (1) the start of the new trip must be no more than 200m from the end of the previous trip; and (2) the start of the new trip must be no more than 10 minutes from the end time of the last trip. Voss et al. (2014) determined the start of the trip as the first point recorded by the GPS outside the home or school with a speed greater than or equal to 1.0km/h and lasting 30 seconds or longer. This variability in the procedures for interpreting GPS data may be due to the urban or social context of the cities or to the characteristics of the sample in which the research was carried out. Moreover, some limitations may appear in these methods such as any trip starting outside home or school buffer zone would not be considered as a home-to-school or school-to-home trip or may misclassify pauses during the trip as end of the trip.

Therefore, to obtain the best data quality during the commuting to/from the school and to overcome these limitations, the shapefiles (i.e., a simple, non-topological format used to store the geometric location and attribute information of geographical entities), where home, school, and trips travelled by each participant are shown, should be analyzed manually one by one –which is highly time demanding- or by using filters to facilitate the analysis of very large samples or many days of data collection. In this way, a higher accuracy in the determination of the home-school or school-home trip based on times and locations (i.e., if the trip starts at home or at school and ends at home or at school, respectively) can be guaranteed. In addition, to facilitate the analysis using shapefiles, a trip diary could also be used in which participants report the times of the trips, although considering possible overestimation or underestimation of these times (Stopher & Greaves, 2010). The algorithm used by the studies included to determine the home-school or school-home trip is not perfect, particularly if the Signal to Noise Ratio (SNR) function of the GPS has not been used. Another possible solution, besides the improvement and/or development of other algorithms to determine the times of the trips, is to try different combinations to define home location, start/end of the trips, or school location, because urban and social factors can be different even in cities of the same country.

Given the limitations of predefined and self-reported time intervals, the use of geolocation devices (e.g., GPS) may provide individualization and objectivity to the definition of the times and locations of the trips for ACS assessment. However, there is a lack of studies comparing the different ways (i.e., predefined time interval, self-reported time interval tools, or via GPS) to define start/end times during the commute to/from school. In addition, it is important to note that other research areas can be inspirational in further developing how to measure ACS-PA. For example, using GPS-based household travel surveys, as well as mode and trip purpose imputation using location-based servies (LBS) data. Validation and calibrating studies, conducting alternatives to identify the start/end time of the trips, are necessary to provide more accurate measures for the ACS.

4.2. How to quantify the ACS-PA: mode, intensity, and volume

The ACS-PA requires the quantification of the mode of commuting to/from school (including the sequencing of the activities [e.g., leave home and walk to the bus stop, take the bus, get off at the bus stop and get to school]), what device was used to assess the ACS-PA intensity (e.g., MVPA, steps) and duration (e.g., how many minutes were at moderate vigorous or light intensity), and how it was used (e.g., placement). Only eight studies reported information about the intensity, the mode of commuting, and the duration of the commuting to/from school, and only one also reported the sequence of activities (i.e., multimodal trips). On the other hand, the rest of the studies only reported the intensity and mode of commuting to/from school. It is noteworthy that all studies that predefined a fixed interval time (see previous section) were unable to report the specific duration of the trips per participant.

Mode of commuting was mainly assessed by self-reported tools among the studies included. Although self-reported measures can be useful for providing qualitative information (e.g., time at which the activity started, type of activity) (Nigg et al., 2020; Sallis & Saelens, 2000), they are not free of bias such as lack of recall or social influence, especially in young people (Sallis & Saelens, 2000). In addition, there is a large heterogeneity of questions to assess the mode of commuting to/from school, which makes it difficult to compare results across studies. As Herrador-Colmenero et al. (2019) concluded in a previous systematic review, it is necessary to standardize the questions to assess ACS through a universal questionnaire. Another solution to assess the mode of commuting may be the use of GPS; actually, Carlson et al. (2015) validated a software that could automatically predict the mode of commuting to/from using GPS data. These authors obtained an accuracy of 72-80% for walking trips and around 73% for cycling trips. Therefore, the combination of GPS and a universal questionnaire will allow researchers to be more accurate in assessing the mode of commuting to/from school.

Our results also showed that only four of these studies included cycling in their analyses. This can be explained by a multitude of factors. For example, walking is the most popular mode of ACS in many developed countries such as Spain (Gálvez-Fernández et al., 2021), New Zealand (Mandic et al., 2017), United States (McDonald, 2007), Canada (Larsen et al., 2009), while cycling to/from school is less common. Other possible reason is the difficulty to properly assess cycling-PA, especially when the accelerometer placement is the hip-waist (Corder et al., 2008). Many studies using accelerometers have reported that children who cycled to school were less physically active during the trip than those who walked to school (Chillón et al., 2010; van Sluijs et al., 2009). However, this is not to say that young people who cycle are less active than those who walk, but rather that in these studies PA during cycling may have been underestimated due to the processing of accelerometry data and/or device placement, among other factors. In addition, our systematic review showed that some of the studies included did not differentiate the ACS mode, which complicates the comparability of results across studies. Given that walking and cycling have been associated with different health benefits (e.g., cycling to school has positive effects in cardiometabolic risk factors, and walking to school does not), behavioral requirements (e.g., cycling to school requires more complex skills than walking) and environmental aspects (e.g., a safe route to school by walking or cycling may have different characteristics), it seems a priority to separate these two modes of commuting in future studies (Rahman et al., 2020; Verhoeven et al., 2016). In fact, many studies have reported inconsistent findings when associating ACS and health indicators due to the combination of cycling and walking as only one unique behaviour in their analysis (Larouche et al., 2014; Ruiz-Hermosa et al., 2018). Moreover, future studies should also focus on the inclusion of new emerging commuting modes, as Cook et al. (2022) indicate that the concept of active commuting in current times is broader than walking or cycling. However, little has been studied on these new modes of commuting assessing device-measured ACS-PA in school context.

Furthermore, it may be interesting to determine the mode of active commuting performed (e.g., cycling, scooting, or walking) with the sequencing of activities, occurring during the whole commuting behavior. In the current review, no studies have used algorithms to determine the mode of ACS. Carlson et al. (2015) noted that by using GPS and the speed it provides, the mode of commuting of the participants can be determined without using self-reported measurements. In the case of the accelerometers, although several algorithms have been used in the literature to determine activities in free-living conditions, none has been used during ACS in free-living conditions. For example, Stemland et al. (2015) validated a software to determine PA in different situations in free-living conditions through data from accelerometers placed on the hip and the thigh, and they concluded that the software showed good estimation in activities such as walking or sitting during non-standardized conditions. Likewise, Chastin & Granat (2010) developed an algorithm for determining sedentary or non-activity time using data from accelerometers placed on the thigh, that could be interesting for predicting passive commuting. Therefore, future studies should focus on testing existing algorithms during the ACS that facilitate the estimation of the mode of commuting to/from school.

To quantify the intensity of ACS-PA the devices-measured PA preferred by the studies included of this systematic review were accelerometers and pedometers. If the mode identified is walking, the intensity of such activity can also be estimated with accelerometers or pedometers. The intensity of cycling is more difficult to measure, yet some studies have proposed its measurement from heart rate sensors (Tarp et al., 2015). Most of the studies included used accelerometers to assess ACS-PA, specifically ActiGraph models. Accelerometers are non-invasive, small in size, and provides data of movement-based PA across the entire intensity spectrum (Liu et al., 2021). Accelerometers can also provide timestamped information on the activity intensity, duration, and type (Ellis et al., 2016; Kerr et al., 2017). Although different studies have reported high accuracy in recognizing activities (e.g., sitting, walking, cycling, or sleeping) using machine-learning models and accelerometry data (Walmsley et al., 2021; Willetts et al., 2018) or the variability of accelerometer angles (Crowley et al., 2019), none of the studies included in this systematic review used this methodology. For example, travel mode was self-reported in all those studies that used only accelerometers.

It is also important to highlight the accelerometer's placement, which is usually determined based on the algorithms that are to be used to assess the behaviour of interest (Burchartz et al., 2020; Migueles et al., 2017). The procedures for using accelerometers vary widely among the studies in our systematic review. For example, most studies included device placement at the hip or waist, as they used hip-based cut-points to assess PA intensity (Stevens et al., 2020). However, this placement also has many disadvantages, such as interference with clothing or the difficulty in quantifying PA in different postures and physical behaviors (e.g., sitting, climbing, etc.) (Ellis et al., 2016; Stevens et al., 2020). New trends in the PA measurement literature include algorithms based on thigh and wrist data (Burchartz et al., 2020). Thigh-worn accelerometers are emerging as a new safe and feasible placement (Stevens et al., 2020). Stemland et al. (2015) and Crowley et al. (2019) reported an excellent accuracy using the accelerometer on thigh placement to identify different PA types, including cycling. Regarding wrist data, Willetts et al. (2018) and Walmsley et al. (2021) showed the development of a tailored machine learning model which predicted walking, cycling, or passive activities (i.e., driving a vehicle) with over 70% success rate.

Furthermore, two of the studies included in our systematic review used pedometers. Pedometers can also provide information about the intensity of the PA performed based on the step cadence (i.e., steps per minute) (Tudor-Locke et al., 2018, 2019, 2020, 2021). Moreover, due to the relatively high cost of accelerometers and since the walking is the main mode of ACS in most countries, pedometers might be a potential tool to evaluate the intensity of when the sample of study mainly commute by walk to/from school (Svarre et al., 2020).

The choice of the device-measured PA may be determined by the study population and the research question. If the mode of commuting of the study sample is expected to be mainly walking, the use of pedometers is more feasible than the use of accelerometers, as they produce similar accuracy as accelerometers at a lower price in most cases. On the other hand, if cycling is the mode of commuting predominant of the study sample or the research question requires the determination of the PA mode, the use of accelerometry would be justified (Ellis et al., 2016; Kerr et al., 2017).

5. Strengths/limitations

The major strength of this systematic review is that it is first to provide an overview of methodologies used to assess ACS-PA through device-measured PA, as well as offering practical applications that may help researchers for future studies. In addition, the present systematic review has other strengths such as: (1) it has followed the recommendations of Gunnell et al. (2020) for conducting systematic reviews, as well as the PRISMA statement (Page et al., 2021); (2) the methodologies used to assess ACS-PA by the different studies have been analyzed in order to provide an overview of what is being used, what the science says about it, and a practical proposal that summarizes both ideas; (3) it offers a proposal to analyze the ACS-PA by defining two concepts: the identification of the times and locations of the trips (i.e., when and where) and how to quantify the ACS-PA (i.e., how much).

However, the present systematic review has several limitations that should be acknowledged. The grey literature was not included, as well as only studies in English and Spanish were included, which could have led to selection bias. Given that there were few studies that evaluated ACS-PA with pedometers or with combined measurement devices – heart rate monitors or GPS measurement-, comparisons between studies were reduced. Also, there was a great diversity of predefined time intervals between studies, which made comparison of results difficult. Finally, very few studies have evaluated cycling PA and, consequently, more studies are needed to determine an appropriate methodology for a correct assessment of cycling-PA to/from school.

6. Practical considerations and future directions

This systematic review is intended to help researchers and practitioners to make decisions and suggest them how to approach their study methodology to assess ACS-PA. After analyzing different methodologies used by the studies included and discussing them with the scientific literature, the decision tree proposed by the authors to improve the assessment of ACS-PA can be found in Fig 2. In addition, future directions for the improvement of the ACS-PA analysis proposed by the authors, regarding the identification of the times and locations of the trips and how to quantify the ACS-PA: mode, intensity, and volume, can be found below.

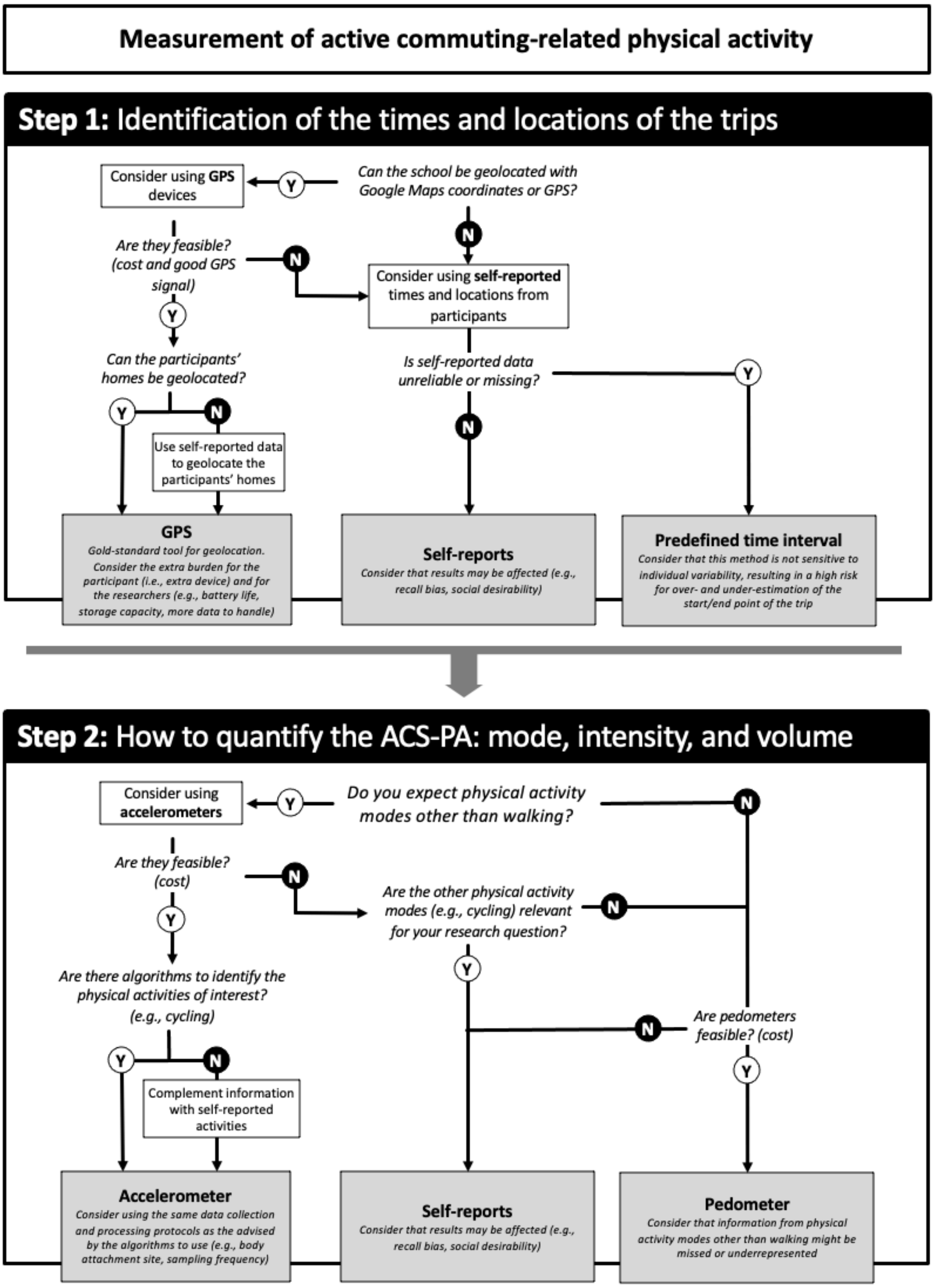

Figure. 2 Decision tree proposed by the authors to improve the assessment of ACS-PA, differentiating the identification of the times and locations of the trips and how to quantify the ACS-PA: mode, intensity, and volume.

6.1. Identification of the times and locations of the trips

Assessing the ACS requires to know when it occurs. The GPS seems to be the right device to measures ACS because of its objectivity and spatial-temporal precision. However, other methods such as predefined time intervals or self-reported travel diaries may be an option, but assuming their potential biases. Methodological studies are needed to validate the predefined time intervals and travel diaries with the GPS data during ACS. Future studies aiming to analyze ACS-PA should combine accelerometers, GPS, Geographic Information Systems (GIS), and self-reporting tools to obtain detailed information on the trips, regarding its spatio-temporal-activity patterns at the individual level.

6.2 How to quantify the ACS-PA: mode, intensity, and volume

Accelerometer and pedometers can appropriately assess ACS-PA, depending on the study sample and the research question. The use of accelerometers requires determining where to place them, being the thigh the position that will allow greater accuracy when determining activities such as cycling. In addition, pedometers might be a good choice to overcome cost and the use of complex software for accelerometers analysis. Finally, future studies should focus on use of machine-learning models and accelerometers or pedometers in free-living conditions, to provide an accuracy assessment of the ACS-PA.

7. Conclusions

The main findings of this systematic review suggest that there is a high degree of heterogeneity among the studies in the methodology used to assess device-measured ACS-PA. Despite the predefined time intervals being the most used method in the studies included to determine the times of the trips, times range from 30 minutes to 180 minutes. In addition, some studies used a GPS trying to determine these times. Regarding how to quantify the ACS-PA, the mode ACS was mainly established by self-reported instruments and the different studies focused more on the assessment of walking than cycling to/from school, and in some cases did not even differentiate between modes of ACS. Moreover, the intensity of the ACS-PA was mainly measured with accelerometers and was usually placed on the hip.

All these results confirm the lack and need for a standardised protocol to assess ACS-PA, because this high heterogeneity makes it difficult to compare the results found between studies. In addition, methodological studies are needed to provide more accurate and appropriate assessments of ACS-PA regarding both the identification of the times and locations of the trips, and how to quantify the ACS-PA (i.e., mode, intensity, and volume). Finally, the authors of this manuscript call for the development of research-grade devices, including both accelerometers and GPS sensors to increase the feasibility of the ACS-PA measurement.

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