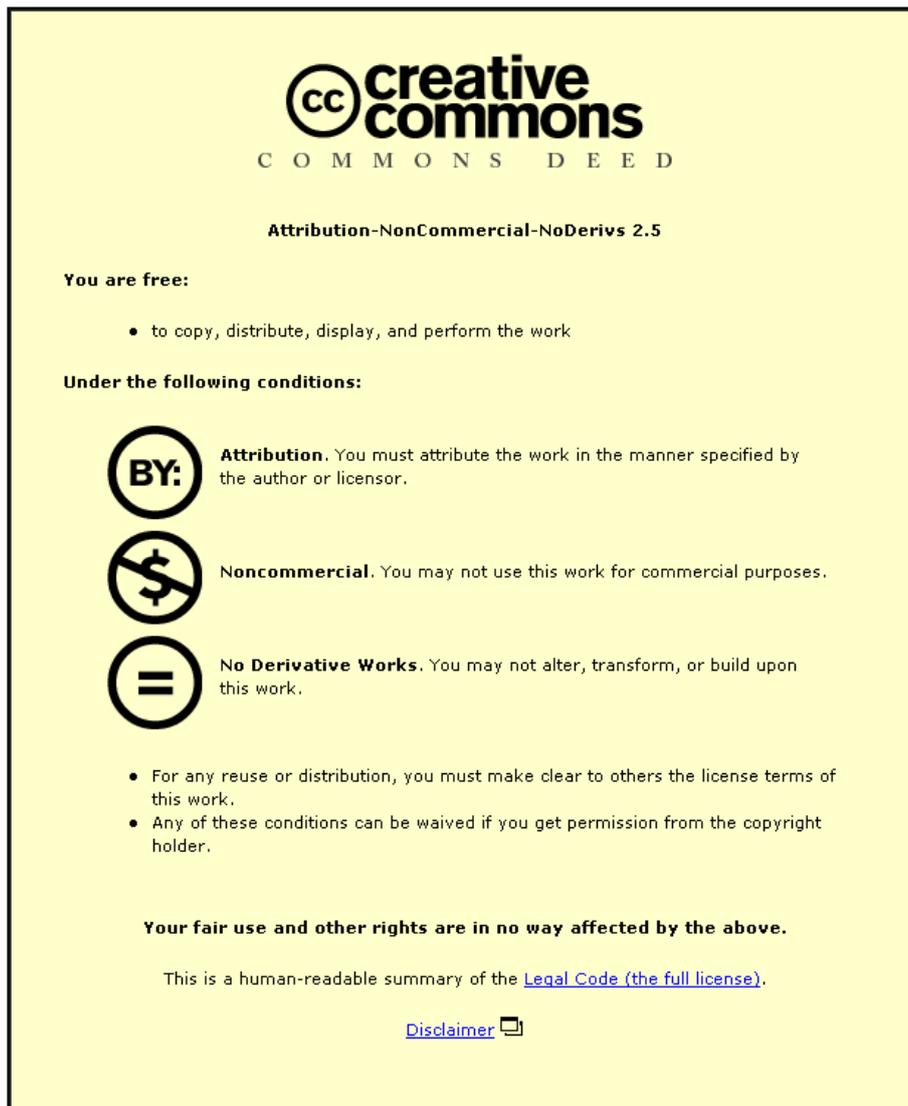


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**The Use of Pedometers for Monitoring Physical Activity in Children and Adolescents:
Measurement Considerations**

Stacy A Clemes and Stuart JH Biddle

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Corresponding Author:

Dr Stacy A Clemes
School of Sport, Exercise and Health Sciences
Loughborough University
Leicestershire
LE11 3TU, UK
Telephone: +44 1509 228170
Fax: +44 1509 223940
Email: S.A.Clemes@lboro.ac.uk

Abstract

Background

Pedometers are increasingly being used to measure physical activity in children and adolescents. This review provides an overview of common measurement issues relating to their use.

Methods

Studies addressing the following measurement issues in children/adolescents (aged 3-18 years) were included: pedometer validity and reliability, monitoring period, wear time, reactivity, data treatment and reporting. Pedometer surveillance studies in children/adolescents (aged: 4-18 years) were also included to enable common measurement protocols to be highlighted.

Results

In children >5 years, pedometers provide a valid and reliable, objective measure of ambulatory activity. Further evidence is required on pedometer validity in preschool children. Across all ages, optimal monitoring frames to detect habitual activity have yet to be determined; most surveillance studies use 7-days. It is recommended that standardised wear time criteria are established for different age groups, and that wear times are reported. As activity varies between weekdays and weekend days, researchers interested in habitual activity should include both types of day in surveillance studies. There is conflicting evidence on the presence of reactivity to pedometers.

Conclusions

Pedometers are a suitable tool to objectively assess ambulatory activity in children (>5 years) and adolescents. This review provides recommendations to enhance the standardisation of measurement protocols.

Introduction

Physical activity in young people is an important public health issue. Increasing levels of physical activity in children and adolescents is a priority if we are to combat the burden of disease associated with physical inactivity, including obesity and rising levels of type 2 diabetes. The accurate measurement of physical activity in children and adolescents, in both surveillance studies and for physical activity promotion is of paramount importance.¹

Pedometers are increasingly being used as a surveillance tool to objectively assess ambulatory (walking) activity levels and patterns in different populations. They enable the accumulative measurement of daily activities, providing a measure of total volume of ambulatory activity.² The combination of their low cost (\$10 - \$160 USD), small size, simplicity and unobtrusive nature make them practical tools for objectively monitoring ambulatory activity in the free-living environment.³ The standardised steps-per-day unit of measurement enjoys universal interpretation, facilitating reliable cross-population comparisons.⁴ Notwithstanding the importance of accelerometers in research and well funded surveillance studies, pedometers offer a practical and cost-effective method for the objective assessment of physical activity and will continue to be an instrument of choice for many. This includes the important role of self-monitoring and motivation, which is made possible by the pedometers easily interpretable and immediately accessible visible display of accumulated step counts, a function not available in accelerometers.

The majority of research-grade pedometers use either a spring-levered or piezo-electric accelerometer mechanism. Spring-levered pedometers contain a spring suspended horizontal lever arm that moves up and down in response to vertical accelerations of the hip. This movement opens and closes an electrical circuit and when the lever arm moves with sufficient

force (above the sensitivity threshold of the specific pedometer) electrical contact is made and a step is registered.^{5,6} Piezo-electric pedometers contain a horizontal cantilevered beam with a weight on one end which compresses a piezo-electric crystal when subjected to accelerations above the sensitivity threshold. This generates voltage proportional to the acceleration and the voltage oscillations are used to record steps.⁵

The use of pedometers for the objective assessment of physical activity in children and adolescents is rapidly increasing. Despite the widespread use of pedometers as a surveillance tool in children and adolescents, Craig et al.² have reported a lack of standardisation in terms of the reporting of pedometer data in earlier studies. For example, it has commonly been reported that boys accumulate higher step counts than girls across all ages and that step counts tend to peak before 12 years of age, after which they decline throughout adolescence.⁷ Given these observations, it will be important to take into consideration age- and sex-related differences when reporting pedometer data. Furthermore, there are also unanswered questions regarding how many days of monitoring are needed to reliably estimate habitual behaviour, how many hours per day constitute a valid day, should we exclude data from a particular day if the pedometer was removed for any duration, and is reactivity a threat to pedometer data collected in children? The present review, therefore, aims to provide a synthesis of common measurement issues relating to the objective assessment of walking behaviour, using pedometers, in children and adolescents. A number of similar approaches to the treatment of pedometer data have been reported in recent surveillance studies and a goal of this review is to provide recommendations for data treatment and processing to aid the standardisation of reporting of pedometer data in future surveillance studies.

Methods

The following electronic databases were searched: PubMed, Science Direct, PsychInfo, Sportdiscus and the Education Resources Information Center (ERIC). The databases were searched using the words 'pedometer' and 'pedometry' in combination with the following keywords: children, adolescents, surveillance, population monitoring, national, regional, reliability, validity, accuracy, youth, and preschool. The search strategy also involved examining the reference lists of the relevant articles found to check for further studies.

The literature reviewed encompassed published articles available in English. The review was confined to articles in peer reviewed journals published between 1996 and 2010. Articles were included in the review if they 1) reported assessing pedometer validity and/or reliability in a sample of children and/or adolescents (up to the age of 18 years); 2) reported investigating a measurement related issue associated with the use of pedometers in children and/or adolescents (up to 18 years), for example the presence of reactivity, or the number of days of monitoring needed to establish habitual activity; and 3) reported using pedometers as a physical activity surveillance tool in relatively large samples ($n > 100$) of healthy free-living children and/or adolescents (up to 18 years).

Results and Discussion

A total of 706 articles were identified from the above search terms. Following elimination of duplicates, 89 articles were retrieved, of these, 16 articles reported testing the validity and reliability of pedometers in children and adolescents, 10 addressed a measurement-related issue associated with the use of pedometers, and 36 reported the use of pedometers in large-scale studies assessing activity levels of children and adolescents (for the purpose of this review, a study was included if pedometer data were collected from at least 100 participants). A

number of measurement-related themes emerged during the review, and the findings are discussed in relation to the following topics: pedometer reliability and validity, number of days of monitoring required, pedometer wear time, reactivity, methods of data treatment, analysis and reporting, and choice of pedometer.

Pedometer reliability and validity

A number of studies have assessed the validity and reliability of pedometers in children and adolescents and the main findings are summarised in Table 1. Four studies examined the use of pedometers in preschool children (aged 3-5 years).⁸⁻¹¹ Following comparisons between pedometer counts and scores from the direct observation of activity, McKee et al.⁸ and Louie and Chan⁹ both concluded that the spring-levered Yamax DW-200 pedometer is a valid and reliable tool for the assessment of physical activity in preschool children. Similar conclusions were drawn by Cardon and De Bourdeaudhuij¹¹ following their study assessing the relationship between accelerometer-based activity minutes and pedometer-determined step counts. Cardon and De Bourdeaudhuij¹¹ reported that almost all children found it 'pleasant' to wear a pedometer, and that compliance with data registration was high. They suggested that daily step counts in preschool children give valid information on daily physical activity levels, which are low in this age range. However, Oliver et al.¹⁰ reported greater variability in pedometer counts at slow walking speeds and have questioned the accuracy of the Yamax pedometer for assessing physical activity in preschool children. Following a review of activity assessment measures in this age group, Oliver et al.¹² noted that the spring-levered Yamax SW/DW-200 pedometer is the only pedometer that has been assessed for validity in preschool children, and the efficacy of other pedometer models/brands has yet to be determined

The majority of pedometer validation studies have been completed on children between the ages of 5 and 12 years (Table 1), and it has generally been concluded that for this age group pedometers provide an inexpensive and valid method for assessing levels of ambulatory activity,^{15,20} particularly when total volume of ambulatory activity is the main outcome of interest.¹⁸ Duncan et al.¹³ reported no differences in pedometer accuracy between 5-7 and 9-11 year olds. Similarly, Nakae et al.¹⁶ reported comparable trends in terms of pedometer accuracy across 7 to 12 year olds at different walking speeds, suggesting that pedometer accuracy is not affected by age in 5 to 12 year olds.

As with adults,²⁵⁻²⁹ in children pedometers have been shown to be less accurate at slower walking speeds (<2.5 mph).^{13,14,16,21} For example, Mitre et al.²¹ tested the accuracy of two pedometers at slow walking paces (0.5, 1.0, 1.5 and 2.0 mph) and observed that they were unacceptably inaccurate at all speeds. However, when participants were asked to walk at a self-selected pace, they chose an average speed of 2.5 mph, and improvements in accuracy were seen at this speed. Duncan et al.¹³ have questioned the practical significance of this common finding since the relationship between slow walking and health benefits in children is not well understood. Furthermore, in studies requesting children to walk at a self-selected pace, it has been observed that children tend to walk faster than the slower speeds applied in treadmill protocols,^{14,21} suggesting that speed-related pedometer error may not be an issue during self-paced walking in children.¹³

The majority of pedometer validation studies in children aged 5 to 12 years have focussed on the spring-levered Yamax pedometer, and this pedometer has been the most widely used in large-scale studies assessing pedometer-determined activity in children (see supplemental table). However, evidence has suggested that pedometers with a piezo-electric mechanism are

more accurate than the Yamax pedometer range.^{5,13,16} For example, Nakae et al.¹⁶ compared the accuracy of the Yamax pedometer with two piezo-electric (Kenz Lifecorder and Omron HJ-700IT) pedometers during self-paced walking in children aged 7 to 12 years. It was observed that the step counts from the Yamax pedometer were significantly lower than actual steps taken at all walking paces (participants each walked at slow, normal and fast walking speeds). The piezo-electric pedometers were more accurate than the Yamax pedometer at all walking paces and steps recorded by the Kenz Lifecorder did not differ significantly from actual steps taken at normal and fast walking paces. Based upon their findings, Nakae et al.¹⁶ have advised that spring-levered pedometers are not appropriate for use in children and they advocate the use of the more accurate piezo-electric pedometers. In a similar study assessing the accuracy of the Yamax SW-200 and the piezo-electric New Lifestyles NL-2000 pedometer during treadmill walking in children, Duncan et al.¹³ observed that the NL-2000 was more accurate than the SW-200 at slow, moderate and fast paces.

Duncan et al.¹³ investigated the influence of body composition on pedometer accuracy and observed no significant relationship between BMI, waist circumference and body composition on pedometer error. They did observe, however, that pedometer tilt angle was associated with the magnitude of pedometer error, particularly with the Yamax pedometer. It was observed that the NL-2000 exhibited superior performance than the Yamax SW-200 at large tilt angles, something which has also been observed in adults.⁵ From their study, Duncan et al.¹³ have proposed that in children, the style of waistband on their clothing is likely to be the largest determinant of pedometer tilt and children with loose fitting clothing may experience a reduction in pedometer accuracy, especially if a spring-levered pedometer is used. It is therefore suggested that fastening the pedometer to a belt could minimise errors associated with pedometer tilt in future studies.

In one of few studies to assess the accuracy and reliability of the Yamax SW-200 pedometer in adolescents, Jago et al.²⁴ observed no significant effect of pedometer placement on accuracy in males. It was concluded that pedometers provide an accurate and reliable assessment of the amount of activity in which adolescents engage. Limited data currently exist, however, on the accuracy of pedometers in female adolescents and further work should be conducted to assess the accuracy of different pedometers (for example piezo-electric versus spring levered) in this population.

The pedometer validation studies summarised in Table 1 have largely focussed on the pedometer output of steps per day, or step counts achieved over a particular period of time. According to Corder et al.³⁰ pedometer output should be expressed as steps per day without any further inference of distance or energy expenditure as the uncertainty in these predictions may be unacceptably high. Trost³¹ has also advised against using energy expenditure estimates from pedometers as the algorithms for these calculations are derived from adults and may not be appropriate for children.

In summary, the evidence suggests that in children above the age of five, pedometers provide a valid and reliable objective measure of total volume of ambulatory activity. Pedometers are most accurate at normal and fast walking paces. Further validation evidence is required before the suitability of pedometers for use in preschool children can be confirmed. The majority of pedometer validation studies have focussed on the spring-levered Yamax pedometer. However, emerging evidence has suggested that pedometers with a piezo-electric mechanism (for example, the New Lifestyles NL series, Kenz Lifecorder, and Omron HJ-700IT), are more accurate than the Yamax pedometer range. Piezo-electric pedometers have been shown to be more accurate than the Yamax pedometer at all walking speeds,¹⁶ and less affected by tilt

angle,¹³ and their use, as opposed to spring-levered pedometers, has been recommended in future studies.¹⁶

How many days of monitoring?

Research assessing physical activity is typically interested in quantifying a person's usual or habitual activity level.³² Day-to-day fluctuations in pedometer-determined ambulatory activity are not random and can, in part, be explained by real life fluctuations in behaviour caused by factors such as attendance at school and participation in sports/physical education. The most appropriate monitoring frame to estimate habitual ambulatory activity of children and adolescents is currently unknown. When considering research design, a balance has to be met between ensuring the monitoring period is sufficient to reliably estimate habitual behaviour without producing unnecessary participant burden.

Few studies have investigated the consistency of pedometer data collected in children and adolescents. Strycker et al.³³ reported that at least five days of pedometer data are needed in a sample of 10 to 14 year olds to reliably (intra-class correlation ≥ 0.8) predict habitual activity (based upon data collected over a period of seven days). Vincent and Pangrazi³⁴ have also reported that at least five days of monitoring are needed to reliably predict pedometer-determined activity in 7 to 12 year olds, although data collection in this study was restricted to after school periods on week days only thus limiting the application of these findings. In contrast to Strycker et al.³³, Rowe et al.³⁵, have reported that at least six consecutive days of monitoring are needed to reliability predict habitual activity in 10 to 14 year olds. Rowe et al.³⁵ also recommend that this six-day monitoring period is preceded by a familiarisation day, and that it includes both weekend days and weekdays. Recently, Craig et al.² have reported that two days of monitoring would be sufficient to achieve acceptable reliability for population estimates of

step counts in a large sample ($n = 11,477$) of 5 to 19 year olds. However, Craig et al.² caution that this recommendation is based upon the reliability of population estimates, and the reliability of step counts at the individual level are likely to require higher standards and thus longer monitoring periods.

In a review of objective measures for the assessment of young people's physical activity, Dollman et al.³⁶ report that one week of pedometer monitoring is necessary to capture habitual activity. In a similar review, Corder et al.³⁰ have reported that there is evidence to suggest that between 4 and 9 full days of monitoring, including two weekend days, are required for reliable estimates of habitual activity in children and adolescents. However, they go on to state that whilst seven days of monitoring seems logical, as compliance decreases with increases in the monitoring period, it may be more feasible to opt for four full days with at least one weekend day. Corder et al.³⁰ acknowledge that their recommendations for an optimal pedometer monitoring frame are based upon the reliability of accelerometer data in children, and not on pedometer data.

When considering appropriate monitoring frames, it is also important to consider seasonal and geographical location differences that impact physical activity levels of children and adolescents.^{37,38} According to Corder et al.³⁰ seasonal variations in activity, resulting from changes in climate, school terms, and school holidays, means that a single measurement period may not adequately reflect a child's habitual activity. It is therefore recommended that if a habitual estimate of activity, defined as an annual average, is required, measurements should take place over more than one season.³⁰

Pedometer wear time

A related issue to the length of monitoring frame is pedometer wear time. It is common practice to ask participants to record in a diary the times in which the pedometer was put on in the morning and taken off at night, along with any other instances throughout the day (including duration) where the pedometer was removed. A number of researchers have excluded data from a particular day, or all of the data from a participant, if participants have reported removing the pedometer for over an hour.^{11,39-50} To enhance comparability between studies it is recommended that future studies apply the same protocol of excluding data from a particular day if participants report removing the pedometer for over one hour on that day.

There is currently no single accepted criterion for the identification of how much wear time is necessary to constitute a valid day of pedometer measurement in children and adolescents.³⁰ Recently, some authors have reported the wear time criteria applied to distinguish a valid day of pedometer monitoring. For example, Drenowatz et al.⁵¹ included participants in their analyses if their 8 to 11 year old children reported wearing the pedometer for at least 10 hours per day on at least four days (including one weekend day) of the 7-day monitoring period. Similarly, Sigmund et al.⁵² required 5 to 7 year olds to wear their pedometer for at least 8 hours per day on every day of the 7-day monitoring period to be included in the analyses. To enhance comparability between studies, it is recommended that authors report wear time criteria that have been applied to constitute a valid day of monitoring. It is also recommended that standardised wear time criteria are established for different age groups to aid the standardisation of protocols for the assessment of pedometer-determined activity in children and adolescents.

Reactivity

When used as a measurement tool, researchers often provide participants with unsealed pedometers (i.e., no restriction on participants viewing their step count) and request that they record their daily step count in an activity diary or step log. However, if activity changes as a result of wearing the pedometer, defined as reactivity,⁵³ this could affect the validity of pedometer-determined activity data. The presence of reactivity is usually examined by studying whether step counts are higher over the first few days of monitoring relative to step counts collected towards the end of the monitoring period. To date, what limited evidence there is provides conflicting reports on the presence of reactivity to wearing pedometers in children and adolescents. Rowe et al.³⁵ reported no evidence of reactivity occurring in response to wearing unsealed pedometers over a period of six days in a sample of 10 to 14 year olds. Adopting a similar approach, Craig et al.² also reported no evidence of reactivity in a nationally representative sample of 5 to 19 year olds when wearing unsealed pedometers for seven days. Similarly, Ozdoba et al.⁵⁴ reported no differences in step counts measured using sealed (where the visible display of the pedometer is restricted) and unsealed pedometers worn for four days in each condition in 9 to 10 year olds, and concluded that reactivity is not a cause for concern in this age group. Vincent and Pangrazi³⁴ also reported no evidence of reactivity occurring in response to wearing sealed pedometers for eight days in 7 to 12 year olds.

A limitation of the studies described above employing sealed pedometers to assess the presence of reactivity, is the fact that in this condition the participants were still aware that they were wearing a pedometer, which in itself may elicit some degree of reactivity. Only when participants are unaware that their activity levels are being monitored (termed covert monitoring) can a true investigation into reactivity be undertaken.⁵⁵ Recent evidence from adults has highlighted a reactive effect occurring in response to wearing unsealed pedometers when

baseline step counts were determined using covert monitoring.^{56,57} A second limitation associated with the above studies is the relatively short monitoring period applied. Ling et al.⁵⁸ have recently assessed the presence of reactivity in response to wearing sealed pedometers (with 7-day memory chips) over a period of three weeks in 9 to 12 year olds. They observed that mean daily step counts recorded during the first week of monitoring were significantly higher than those recorded during the third week of monitoring, and suggested that a reactive effect did occur during the first week. Using a different approach to determine the presence of reactivity in response to wearing unsealed pedometers in third to fifth grade children, Beets et al.⁵⁹ retrospectively questioned children and their parents on whether changes in activity levels (child) occurred or were observed (parent) whilst the child wore an unsealed pedometer. It was concluded from this study that both parents and children perceived a reactive effect in response to wearing an unsealed pedometer. Further research using covert monitoring with pedometers with memory chips, along with extended monitoring periods, should therefore be conducted into the presence of reactivity in children, as reactivity, if present, could have validity implications for short term studies investigating young people's habitual activity.

Methods of data treatment, analysis and reporting

A number of studies have successfully used pedometers for the assessment of ambulatory activity in children and adolescents³⁰ and these studies are summarised in the supplementary table. The primary findings, in terms of mean daily step counts, along with the type of pedometer worn, the sample studied and compliance data (where available) are also summarised. From the studies reviewed, the monitoring frames ranged from 3 to 8 days, with monitoring periods of seven days being the most common. From those studies providing compliance data, compliance ranged from 46 to 99%. Thirteen (50%) studies with compliance data reported participant compliance rates above 90%. Some studies restricted data collection

to weekdays only,^{44,47,49,60-63} whereas others included data collected on both weekdays and weekend days.^{11,33,35,37,39-43,50,51,64-67} Significant differences in activity have been reported between weekdays and weekends, with decreases in activity generally being reported during the weekends,^{37,40-42,66,67} with the exception of one study which showed the opposite.⁵⁰ From the studies reporting a decrease in activity on weekends, on average step counts declined by 20% (range: 6-30%) on weekend days in comparison to weekdays. It is therefore recommended that for studies interested in determining habitual activity that step count data are collected on both weekdays and on weekend days.

A number of studies reviewed applied specific criteria to pedometer data during data processing to ensure the reliability and quality of the data. For example, Rowe et al.³⁵ have recommended upper and lower cut-offs for identifying outliers, of fewer than 1000 steps and greater than 30000 steps. They recommend that data points (step counts) falling beyond these cut-points are treated as missing data. A number of studies have subsequently adopted these cut-points and applied them during data treatment and analysis.^{37,39,40,42,64,67,74} Craig et al.² have recently investigated the proportion of children's pedometer data falling outside of these cut-points and examined the effects of truncating step counts outside of this range to these values. They reported that removal of step counts <1000 and >30000 had little impact on the overall derived population estimates for young peoples' mean daily step counts and concluded that this form of data manipulation does not appear to be warranted in terms of population estimates of pedometer-determined physical activity. Craig et al.² have recommended that researchers report raw estimates of daily step counts in future surveillance studies to enable comparisons across studies and different populations.

As highlighted, pedometer output should be expressed as the number of steps accumulated per day (steps/day), and this has been the predominant method of reporting pedometer data in the surveillance studies reviewed. An advantage of pedometers is the fact that their relatively simple output, in terms of steps/day, makes it straight forward to compare walking levels between populations and between studies due to the limited number of data reduction techniques required to summarise this type of data.³⁰ Depending upon the research question, study authors report collecting participant's daily step count and using these daily values to calculate the mean step count for each participant over the course of the monitoring period. Using the mean step counts for all participants within the study, or within a particular demographic group (e.g. boys/girls), the mean daily step count for the sample as a whole (or sub-group) are calculated and reported. The majority of studies reviewed have reported that boys have significantly higher daily step counts than girls, at all ages, with boys on average accumulating 15% more steps/day (range: 3-36%) than girls. It is therefore common practice to report mean daily step counts for boys and girls separately. Other categorisation variables commonly applied where appropriate include age group or school year/grade and BMI since it has been reported that step counts decline with increasing age^{39,46,52,75} and BMI.^{50,63} Ethnic differences in step counts have also been reported,⁴⁷ therefore where relevant it may also be important to report step count data according to ethnicity.

In addition to reporting mean daily step counts of the sample, a number of researchers have reported the percentage of participants achieving a particular step count.^{41,71} A limitation of this approach, however, is the fact that there are currently no validated step count cut-offs for children and adolescents. A number of studies have used different cut-points thereby eliminating the possibility of making comparisons across studies of the number of participants achieving particular cut-points. For example, Vincent and Pangrazi⁶⁰ have recommended that a

reasonable standard for girls and boys aged 6 to 12 years is to accumulate 11000 and 13000 steps/day, respectively. However, Tudor-Locke et al.⁷⁸ have recommended that 6 to 12 year old girls and boys accumulate 12000 and 15000 steps/day. Recently Tudor-Locke et al.⁷ have suggested that there is no single steps/day cut-off that spans across all ages of children and adolescents. They report that as a preliminary recommendation male primary/elementary school children should accumulate 13,000 to 15,000 steps/day, female primary/elementary school children should accumulate 11,000 to 12,000 steps/day, and adolescents should accumulate 10,000-11,700 steps/day. Given the differences in step count recommendations reported in the literature, and until more is known about the dose-response relationship between step counts and various health parameters,⁷ it is recommended that researchers apply caution when interpreting their findings in terms of the proportion of participants achieving a particular step count.

Choice of pedometer

The most widely used pedometer in large-scale surveillance studies to date has been the spring-levered Yamax pedometer range. Recently, however, some researchers have used the piezo-electric New Lifestyles NL-2000 pedometer in large studies.^{39,40,42} The advantage of this pedometer over the Yamax SW range is the NL-series 7-day memory capacity, making this pedometer capable of storing step counts in 1-day epochs. This is particularly useful for those studies employing the use of sealed pedometers. It should be noted however that newer models of the Yamax pedometer (for example, the CW-700 which uses the same internal mechanism as the SW-200) also now includes a 7-day memory chip, although the use of this device is yet to be reported in the literature.

When gathering pedometer data there is always a risk of participants tampering with the pedometer, for example by shaking it to give the illusion of more steps, or accidentally hitting the reset button and losing data. Clearly, such things can compromise the integrity of the data.²² When comparing step counts derived from sealed and unsealed pedometers in 9 to 10 year olds, Ozdoba et al.⁵⁴ reported more usable days of data being obtained from the sealed condition and have therefore recommended the use of sealed pedometers in research studies, particularly in studies wishing to monitor free-living activity. A number of surveillance studies (53%) included in the Supplementary Table have used sealed pedometers, which are likely to yield more reliable data in children and adolescents, at a cost of increased researcher burden when the pedometer used has no memory function. For example, the most common practice applied with the use of sealed pedometers (with no memory function) is for the researcher to collect the pedometer from the participant at a set time each morning (usually upon arrival at school), unseal the pedometer and record the step counts measured from the previous day, and then return the re-sealed pedometer back to the participant. This researcher burden is eliminated, however, when pedometers with multi-day memory functions are used, and it is recommended that for future studies wishing to use sealed pedometers, researchers consider using pedometers with multi-day memory functions.

Summary and recommendations

The evidence from this review suggests that in children above the age of five, pedometers provide a valid and reliable objective measure of children's total volume of ambulatory activity. However, further validation evidence is required before the suitability of pedometers for use in preschool children can be confirmed. The relative low cost of pedometers makes them a feasible measurement tool for use in large-scale epidemiological and surveillance studies^{2,30} where total volume of ambulatory activity is a desirable outcome. Pedometers have relatively

low burden for both the researcher, in terms of initialisation of the device and data output, and for the participant, in terms of recording their daily step count at the end of the day. Compliance to pedometer protocols has generally been good.

The majority of pedometer validation studies (reviewed in Table 1) have focussed on the spring-levered Yamax pedometer, and this pedometer has been the most widely used in surveillance studies assessing pedometer-determined activity in children. However, evidence has suggested that pedometers with a piezo-electric mechanism are more accurate than spring-levered pedometers and their use has been recommended in future studies.¹⁶

Optimal monitoring frames to detect habitual activity in youth have yet to be determined, however the most common monitoring frame used in surveillance studies has been seven consecutive days. There is currently no accepted criterion for the identification of how much wear time is necessary to constitute a valid day of pedometer measurement in children and adolescents. To enhance comparability between studies it is recommended that authors report their wear time criteria applied to constitute a valid day of monitoring. It is also recommended that standardised wear time criteria are established for different age groups to aid further the standardisation of protocols for the assessment of pedometer-determined activity in children and adolescents. It has been common practice to exclude pedometer data from a day when a participant reports not wearing the pedometer for over one hour on that particular day. To enhance further the standardisation of processing and reporting of pedometer data, it is recommended that future studies apply the same protocol in terms of excluding data from a particular day where the participant reports removing the pedometer for over one hour. A number of researchers have excluded step counts below 1000 steps/day and above 30000 steps/day, and treated this as missing data. However, there have been recent calls for

researchers to report raw estimates of daily step counts in future surveillance studies to enable comparisons across studies and different populations.²

Evidence suggests that children and adolescents accumulate significantly fewer steps during the weekends, and it is recommended that for an accurate indication of habitual activity, pedometer data should be collected throughout both weekdays and weekend days. There is evidence to suggest that mean daily step counts decline with age, and it is recommended that for studies examining a wide age range, data are reported according to different age groups. Similarly boys generally report significantly higher mean daily step counts than girls across all ages, and it has become common practice to report and analyse boys and girls pedometer data separately. Finally, studies investigating the presence of pedometer reactivity have produced conflicting results in children. Further work applying covert monitoring with memory chip pedometers and extended monitoring periods should be conducted to determine whether reactivity is a threat to the validity of pedometer-determined activity data collected in children and adolescents.

A limitation of pedometers, like accelerometers, is the fact that they only detect ambulatory activity and are insensitive to non-locomotor forms of movement,^{31,36} for example, cycling. Furthermore pedometers are not capable of distinguishing levels of activity intensity, duration, or frequency of activity bouts undertaken throughout the day.³⁰ They are also susceptible to tampering/data loss³⁶ which could be a larger problem when used with children as opposed to adults, because they may be viewed as an interesting 'toy' to take apart. However, this can partly be overcome by the use of sealed pedometers.

Despite these limitations, according to McClain and Tudor-Locke,⁶ given young peoples' activity patterns are often described as consisting of sporadic and/or intermittent bursts of intense movements, and given the public health focus of accumulating physical activity throughout the day, the cumulative record of daily steps provided by a pedometer is a suitable marker to measure and track in children and adolescents.

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Table 1. A summary of the studies assessing pedometer validity in children, presented according to chronological age of the sample surveyed.

Authors	Sample	Aim/pedometer	Criterion measure	Results/conclusions
McKee et al. ⁸	13 boys, 17 girls, 3-4 yrs	Validity of the Yamax DW-200 in preschool children.	CARS	Correlation between direct observation and pedometer counts: $r = 0.64-0.95$.
Louie and Chan ⁹	86 boys, 62 girls, 3-5 yrs	Validity of the Yamax DW-200 in preschool children.	CARS	Correlation between direct observation and pedometer counts during free play: $r = 0.64$.
Oliver et al. ¹⁰	7 boys, 6 girls, 3-5 yrs	Validity of the Yamax SW-200 in preschool children.	CARS, hand tallied steps during walking.	Correlation between direct observation and pedometer counts during free play: $r = 0.59$. Accuracy decreased at slower walking paces.
Cardon and De Bourdeaudhuij ¹¹	37 boys, 39 girls, 4-5 yrs	Compare daily pedometer (Yamax SW-200) counts with accelerometer-determined minutes in MVPA.	ActiGraph accelerometer	Correlation between daily pedometer step counts and minutes in MVPA: $r = 0.73$.
Duncan et al. ¹³	43 boys, 42 girls, 5-7 and 9-11 yrs	Effects of walking speed, age and body composition on accuracy of a spring-levered (Yamax SW-200) and piezo-electric (NL-2000) pedometer.	Hand tallied steps	Both pedometers were acceptably accurate during moderate and fast walking, but underestimated steps at slow walking. The NL-2000 was more precise than the SW-200. No effects of age or body composition.

Beets et al. ¹⁴	10 boys, 10 girls, 5-11 yrs	Accuracy of the Walk4Life LS2025, Yamax SW-200, Sun TrekLINQ and Yamax SW-701 pedometers.	Hand tallied steps	The Walk4Life and the two Yamax pedometers exhibited a high degree of accuracy at treadmill speeds of ≥ 2.5 mph.
Kilanowski et al. ¹⁵	7 boys, 3 girls, 7-12 yrs	Validity of the Yamax SW-200 pedometer during recreational PA and classroom activities.	TriTrac triaxial accelerometer and CARS	Pedometer vs accelerometer: recreation $r = 0.98$, classroom $r = 0.5$; pedometer vs observation: recreation $r = 0.8$, classroom $r = 0.97$.
Nakae et al. ¹⁶	201 boys, 193 girls, 7-12 yrs	Accuracy of spring-levered (Yamax EC-200) and piezo-electric (Kenz Lifecorder and Omron HJ-700IT) pedometers.	Hand tallied steps	Step counts from the EC-200 were significantly lower than actual steps at all paces. Piezo-electric pedometers were less accurate at slow speeds, but highly accurate during normal and fast walking.
Treuth et al. ¹⁷	68 girls, 8-9 yrs	Comparison between pedometer (Yamax SW-200) step counts and accelerometer activity counts.	ActiGraph accelerometer	Correlation between pedometer steps/minute and accelerometer counts/minute was $r = 0.47$
Louie et al. ¹⁸	21 boys, 8-10 yrs	Validate pedometry (Yamax DW-200), heart rate and accelerometry for predicting energy expenditure.	VO ₂	Hip worn pedometer: $r = 0.77-0.93$, ankle worn pedometer: $r = 0.68-0.92$, wrist worn pedometer: $r = 0.29-0.82$.
Rowlands et al. ¹⁹	17 boys, 17 girls, 8-10 yrs	Assess the relationship between activity levels, aerobic fitness, and	TriTrac triaxial accelerometer	Correlation between accelerometer and pedometer (Yamax DW-200) counts: $r = 0.85$ for boys and $r = 0.88$

		body fat in children.		for girls.
Eston et al. ²⁰	15 boys, 15 girls, 8-11 yrs	Validate pedometry (Yamax DW-200), heart rate and accelerometry for predicting energy expenditure.	VO ₂	Hip worn pedometer: r = 0.81, ankle worn pedometer: r = 0.79, wrist worn pedometer: r = 0.67.
Mitre et al. ²¹	13 boys, 14 girls, 8-12 yrs	Accuracy of the Omron HJ-105 and Yamax SW-200 pedometer at 0.5, 1.0, 1.5 and 2.0 mph.	Hand tallied steps	Both pedometers were unacceptably inaccurate at all speeds. Inaccuracy was greater in overweight children.
Graser et al. ²²	77 children, 10-12 yrs	Determine whether the accuracy of the Walk4Life LS2505 pedometer changes according to placement.	Hand tallied steps	Recommended pedometers are worn on the midaxillary line, on the right. Accuracy was improved when pedometers were worn on a belt.
Scruggs ²³	144 boys, 144 girls, 11–13 yrs	Evaluate step and activity time outputs of the Walk4Life LS2505 pedometer.	Yamax SW701 (steps/min), SOFIT (activity time)	LS2505 significantly underestimated steps/minute and overestimated PA time.
Jago et al. ²⁴	78 boys, 11-15 yrs	Pedometer (Yamax SW-200) validity at different body locations (right hip, left hip, directly above the umbilicus).	ActiGraph accelerometer	No effects of pedometer placement on step counts were observed. Pedometers provide a reliable and accurate assessment of PA in adolescents.

Abbreviations: CARS – Children's activity rating scale; MVPA – moderate to vigorous physical activity; PA – physical activity; r – correlation coefficient; VO_2 – Oxygen consumption; SOFIT - System for Observing Fitness Instruction Time.

Supplement Table. A summary of large-scale studies (>100 children/adolescents) that have used pedometers to assess habitual activity in children and adolescents, presented according to chronological age of the sample surveyed.

Authors	Sample	Pedometer and monitoring frame	Main findings – Mean daily step count (steps/day) of the samples studied	Compliance
Cardon and De Bourdeaudhuij ¹¹	59 boys, 63 girls, 4-5 yrs. Flanders, Belgium	Yamax SW-200, worn unsealed for 5 days	Whole sample: 9980, boys: 10121, girls: 9867 (p>0.05).	95%
Tanaka and Tanaka ⁶⁸	127 boys, 85 girls, 4-6 yrs. Tokyo, Japan.	Lifecorder EX worn for 6 days.	Whole sample: 13037, boys: 13650, girls: 12255 (p<0.05).	74%
Sigmund et al. ⁵²	92 boys, 84 girls, mean age at pre-school: 5.7 yrs, first-grade 6.7 yrs. Moravian region, Czech Republic.	Yamax SW-200, worn unsealed for 7 days, monitoring repeated 1 yr later.	Pre-school children: boys, weekdays: 11 864, weekend days: 11182; Girls, weekdays: 9923, weekend days: 10606. First-grade children: boys, weekdays: 8252, weekend days: 7194; Girls, weekdays: 7911, weekend days: 6872.	72%
Duncan et al. ⁴⁰	536 boys, 579 girls, 5-12 yrs. Auckland, New Zealand	New Lifestyles NL-2000, worn sealed for 7 days	Boys: weekday 16132, weekend 12702, girls: weekday 14124, weekend 11158 (day and sex p<0.05).	91%
Duncan et al. ⁴²	1513 girls, 5-16 yrs, Auckland, New Zealand.	New Lifestyles NL-2000, worn sealed for	Weekday: 12597 weekend: 9528.	92%

		7 days		
Craig et al. ^{2,37}	11669 children, 5-19 yrs. Canada	Yamax SW-200, worn unsealed for 7 days	Boys: 12259, girls: 10906	58%
Belton et al. ⁵⁰	153 boys, 148 girls, 6-9 yrs. Dublin, Ireland.	Yamax SW-200, worn sealed for 7 days	Whole sample: 15760, Boys: weekday 11463, weekend 37009, girls: weekday 10434, weekend 32768 (day and sex p<0.05). Normal weight: 16281, overweight: 13859, obese: 12937.	60 – 96% depending on analyses
Vincent and Pangrazi ⁶⁰	325 boys, 386 girls, 6-12 yrs. Southwest US	Yamax SW-200, worn sealed for 4 days	Boys: 13162, girls: 10923 (p<0.05).	75%
Vincent et al. ⁴⁴	325 boys, 386 girls (US), 278 boys, 285 girls (Australia), 356 boys, 324 girls (Sweden), 6-12 yrs.	Yamax SW-200, worn sealed for 4 days.	Boys: range 15673-18346 (Sweden), 13864-15023 (Australia), 12554-13872 (US). Girls: range 12041-14825 (Sweden), 11221-12322 (Australia), 10661-11383 (US).	
Laurson et al. ⁶⁹	358 boys, 454 girls, 6-12 yrs, Lakeville, MN and Cedar Rapids, IA, US	Yamax SW-200, worn unsealed for 7 days.	Boys: 12736, girls: 10852 (p<0.01).	59%
Le Masurier et al. ⁴⁶	793 boys, 1046 girls, 6-18 yrs.	Yamax SW-	Boys: range 12891-10329, girls: range 11237-	

	Phoenix, US.	200/Walk4Life LS2525, worn sealed for 4 days	9067. Elementary students accumulated more steps/day than middle and high school students.	
Mitsui et al. ⁶⁶	73 boys, 72 girls, 7-11 yrs, Hashikami Town, Japan.	Yamasa EM-180, worn unsealed for 14 days	Boys, school days: 13586, weekend days: 9531, Girls, school days: 12248, weekend days: 9419	99%
Raustorp et al. ⁷⁰	457 boys, 435 girls, 7-14 yrs. Kalmar, Oskarshamn and Morbylanga, Sweden	Yamax SW-200, worn sealed for 4 days	Boys: range 14911-18346, girls: range 12238- 14825 (p<0.05).	96%
Hands and Parker ⁶⁴	787 boys, 752 girls, 7-15 yrs. Western Australia	Yamax SW-700, worn sealed for 8 days	Boys: 13194, girls: 11103 (p<0.05).	68%
Telford et al. ⁶⁷	389 boys, 387 girls, mean age 8.0 yrs during first measurement. Protocol repeated at 2 and 3 yr follow- up. Canberra, Australia.	Walk 4 Life DUO, unsealed yr 1. New Lifestyle AT-82, sealed yrs 2 and 3. 7 days of monitoring.	Median steps: boys: yr 1 12014, yr 2 10564, yr 3 11092. Girls: yr 1 9795, yr 2 8475, yr 3 9086. Across all measurement periods, step counts were significantly lower on weekend days.	
Drenowatz et al. ⁵¹	117 boys, 154 girls, 8-11 yrs. Iowa, US	Yamax SW-200, worn unsealed for 7 days	Boys: 12086, girls: 10053 (p<0.001)	46%

Duncan et al. ⁴¹	101 boys, 107 girls, 8-11 yrs, Birmingham, UK.	New Lifestyles NL-2000, worn sealed for 4 days	Boys: weekday 14111, weekend 10854, girls: weekday 13159, weekend 9922 (day and sex $p < 0.05$).	90%
Al-Hazzaa ⁶³	296 boys, 8-12 yrs. Riyadh, Saudi Arabia	Yamax SW-701, worn unsealed for 3 days	Whole sample: 13489, normal weight boys: 14271, obese boys: 10602 ($p < 0.01$).	
Eisenmann et al. ⁷¹	267 boys, 339 girls, mean age: 9.6 yrs. Midwest US.	Yamax SW-200, worn unsealed for 7 days	Boys: 12709, girls: 10834 ($p < 0.01$). children not meeting step count guidelines were two times more likely to be overweight/obese.	63%
Munakata et al. ⁷²	105 boys, 111 girls, 9-10 yrs. Tokushima, Japan	Lifecorder EX (no more information provided)	Boys: 14929, girls 12389 ($p < 0.001$).	
Coppinger et al. ⁴⁸	42 boys, 64 girls, 9-11 yrs. London, UK.	Yamax SW-200, worn sealed for 3 days.	Boys: 11959, girls: 10938. Steps in the same sample at 1 year follow-up: Boys: 12175, girls: 10395.	88%
Drenowatz et al. ⁷³	268 girls, 9.5-11.5 yrs. Lakeville, MN and Cedar Rapids, IA, US	Yamax SW-200, worn unsealed for 7 days	Whole sample: 10822. Early maturing girls had lower step counts than average and late maturing girls, but these differences were not independent of BMI.	

Maher et al. ⁷⁴	1029 boys, 1042 girls. 9-16 yrs, Australia	New Lifestyles NL-1000, worn for 7 days	Step counts stratified by 4 income bands: 1 (wealthiest): 11196, 2: 11066, 3: 10671, 4 (poorest): 10735.	
Chia ⁷⁵	350 boys, 527 girls, 9-18 yrs. Singapore.	Yamax SW-200, worn unsealed for 7 days.	Boys: age 9-12 yrs: 13563, 13-16 yrs: 9913, 17-18 yrs: 8766. Girls: age 7-12 yrs: 8668, 13-16 yrs: 8637, 17-18 yrs: 8061	97%
Johnson et al. ⁴⁷	273 boys, 309 girls, 10-11 yrs. South-western state, US	Yamax SW-200 and Walk4Life 2505 worn sealed and unsealed for at least 5 school/week-days.	Boys: 12853, girls:10409 (p<0.001). Ethnic differences: African American: 10709, Caucasian: 11668, Hispanic: 11845. Differences by metro status: Urban: 10856, Suburban: 12297, Rural: 11934.	
Rowe et al. ³⁵	299 children, 10-14 yrs. North Carolina, US.	Yamax SW-200, worn unsealed for 6 days	Whole sample: 9338	96%
Strycker et al. ³³	183 boys, 184 girls, 10-14 yrs. Pacific Northwest, US.	Yamax SW-200, worn unsealed for 7 days	Whole sample: 10365, boys: 11283, girls: 9472 (p<0.001).	98%
Loucaides et al. ⁶⁵	109 boys, 123 girls, 11-12 yrs, Cyprus	Yamax DW-200 worn unsealed for 5 days during summer &	Boys: summer 17651, winter 15763, girls: summer 13701, winter 11361 (season and sex p<0.05).	91-86%

		winter		
Loucaides et al. ⁶¹	116 urban and 96 rural children, 11-12 yrs. Cyprus	Yamax DW-200, worn sealed for 4 days during summer & winter	Urban children: summer 14531, winter 13583; rural children: summer 16450, winter 12436. Significant interaction between season and location.	88%
Hohepa et al. ³⁹	95 males, 141 females, 12-18 yrs. Auckland, New Zealand	New Lifestyles NL-2000, worn sealed for 7 days	Boys: 10849, girls: 9652 (p<0.01). Juniors: 11079, seniors: 9422 (p<0.01).	72%
Raustorp and Ekroth ⁴⁹	2000 cohort: 124 boys, 111 girls; 2008 cohort: 79 boys, 107 girls. Both cohorts aged 13-14 yrs. South eastern Sweden.	Yamax SW-200, worn sealed for 4 weekdays	Boys, cohort 2000: 15623, cohort 2008: 15174. Girls, cohort 2000: 12989, cohort 2008: 13338.	76 and 96%
Hands et al. ⁷⁶	330 boys, 362 girls, mean age: 14.1 yrs. Western Australia.	Yamax SW-200, worn unsealed for 7 days	Whole sample: 10747, boys: 11655, girls: 9920 (p<0.001).	
Van Dyck ⁷⁷	47 boys, 73 girls, 12-18 yrs.	Yamax SW-200, worn	Adolescents living in an urban neighbourhood:	

	Flanders, Belgium.	unsealed for 7 days	12055; adolescents living in a suburban neighbourhood: 13426 (p>0.05).	
Lubans and Morgan ⁶²	119 adolescents, 14-15 yrs, New South Wales, Australia	Yamax SW-701, worn sealed for 4 days	Boys: 11865, girls: 9466 (p<0.01).	95%
Wilde et al. ⁴⁵	179 males, 190 females, 14-18 yrs, US	Yamax DW-200, worn sealed for 4 days.	Boys: range from grades 9-12 10329-11564, girls: range 9068-10986.	61%
Schofield et al. ⁴³	415 girls, 15-16 yrs, Central Queensland, Australia.	Yamax SW-700, worn sealed for 4 days	Whole sample: 9617.	90%