

# Measuring activity levels of young people: the validity of pedometers

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The valid measurement of physical activity has the potential to be a very useful tool in countering the obesity epidemic. Previously, reviews have been carried out to investigate the validity of pedometers among adults. This paper aimed to carry out a similar review among children. A literature search was performed in PubMed, Web of Science, PsycINFO, CINAHL and SportDISCUS. Here, 25 papers investigating the validity, reliability and feasibility of pedometers for children were included in the study. Pedometers correlated highly in terms of both criterion (direct observation) and convergent validity (heart-rate monitor, accelerometer). Intra- and inter-unit reliability was also consistently high. Few studies report on feasibility issues of pedometer use in children, particularly compliance, reactivity and dealing with missing data. Given that they are both cheap and easy to use, pedometers can be effectively utilized as a valid determinant of physical activity levels among children and adolescents, particularly in large-scale epidemiological studies. There remains a need for accepted outliers and proper protocol regarding missing data.

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## Introduction

It is widely recognized that the prevalence of childhood obesity is increasing worldwide. This is supported by the results of a number of studies that highlight increased overweight and obesity in the UK<sup>1</sup> and other countries such as the USA,<sup>2,3</sup> Spain<sup>4</sup> and Denmark.<sup>5</sup> According to the Centre for Disease Control & Prevention, worldwide obesity rates have doubled among children and tripled among adolescents since 1980.<sup>6,7</sup>

Opposite trends have been found regarding physical activity among children and adolescents. The rate of physical activity in children/

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adolescents is declining,<sup>8,9</sup> and the rate of energy expenditure among children is 25% lower recommended.<sup>8</sup> In the UK, only 33 and 21% of boys and girls, respectively, are reaching current government physical activity guidelines.<sup>1</sup> There is also evidence that current activity guidelines underestimate the amount of activity needed to maintain a healthy lifestyle.<sup>10</sup>

On the basis of the above trends and a basic interpretation of the energy balance equation,<sup>11</sup> there is a strong case to suggest that obesity is associated with inactivity. A recent systematic review by Reichert *et al.*<sup>12</sup> found that physical activity had a protective effect on adiposity in children.

The effective measurement of physical activity among children and adolescents, for both intervention and observational studies, and in monitoring and promoting physical activity with a view to countering the obesity epidemic, is of great importance. One of the more commonly used and readily available methods of physical activity assessment is the pedometer. Pedometers are cheap, easy to use devices that give a reading of steps. Typically, they measure steps by using a spring-suspended mechanical lever that moves up and down in response to vertical displacement. Each of these movements is recorded and usually displayed digitally. Pedometers can also provide a number of derived output readings. These vary depending on the brand, and include distance travelled, calories expended and time spent at specific activity intensities.<sup>13</sup> These additional features are estimates and have not been validated among children.

Given their low cost, pedometers are practical for use in large-scale epidemiological studies. They have the potential to be a very useful method of measuring activity and provide valuable information to potentially counter obesity. However, as with all evaluation tools, their effective use is dependent on pedometers being validated as an accurate and reliable determinant of physical activity levels. Previous studies have been conducted reviewing the validity of pedometers. However, these have differed in that they have investigated a number of different methods of physical activity measurement<sup>14</sup> or looked at the validity of pedometers among adults.<sup>15</sup> This study aims to review all published papers investigating the validity, reliability and feasibility of pedometers as determinants of physical activity among children and adolescents.

## Methods

### *Search strategy*

The electronic databases PubMed, Web of Science, PsycINFO, CINAHL and SportDiscus were used to search for articles that satisfied the inclusion criteria. The search was limited to articles from 1990 to

the present date, given that the technology used in pedometers is constantly evolving and the current technology only began being reported in the mid-1990s. The specific search strategy consisted of three unique searches of similar terms, separated by the Boolean term OR: 'pedometer OR pedometers OR pedometry'; 'validity OR accuracy OR reliability OR feasibility OR reactivity'; 'children OR adolescents'. These three separate searches were then combined using the Boolean term AND to gather all possible papers and prevent duplication. Results were compared across all five search engines and again, any duplicates removed. The titles and abstracts from all identified papers were assessed to determine their appropriateness for the research question. Full manuscripts of the articles deemed relevant and adhering to the inclusion and exclusion criteria were ordered. The reference lists of these papers were then cross-checked to identify any possible additional publications not previously found.

### *Inclusion and exclusion criteria*

The inclusion criteria were:

- studies reporting the validity, reliability, consistency or accuracy of pedometers and step count monitors;
- full text, English language publications;
- studies of males or females of any ethnicity between the age of 4–20 years.

The exclusion criteria were:

- case reports, editorials, comments, letters, abstracts and systematic and other review papers;
- studies not looking at the accuracy, reliability, consistency or validity of pedometers;
- unpublished or non-English language publications;
- studies with adults or people with medical conditions as subjects.

### *Data extraction and assessment*

The data extracted from each paper included:

- study design;
- sample size;
- population characteristics;
- main outcomes [ $r$  and interclass correlation (ICC) values];
- relevant limitations;

The effectiveness of pedometers among children was addressed under the following headings:

### **Validity**

Convergent validity refers to the extent to which the output of one instrument correlates with the output of other instruments that should, theoretically, be measuring the same exposure of interest.<sup>15</sup> In this instance, the convergent validity of a pedometer can be ascertained by comparing it to self-report questionnaires, heart rate monitors and accelerometers—all of which measure physical activity. Criterion validity refers specifically to the comparison of a method to the most valid assessment method available, the gold or criterion standard.<sup>15</sup> There is currently no universally agreed upon method for physical activity measurement. There is a valid argument for a number of different methods, mainly direct observation, doubly labelled water technique or indirect calorimetry.<sup>16</sup> It is important for researchers to consider what element of physical activity they wish to assess. Direct observation is a better reference point in terms of step count measurement<sup>17</sup>, whereas the other two methods are more suited to the measurement of energy expenditure.

Validity can be quantified using Pearson's product-moment correlation coefficient ( $r$ ). Other output measures of validity are percentage accuracy/error and ICC. A general guideline is that an  $ICC \geq 0.75$  is deemed good.<sup>18</sup>

### **Reliability**

This covers a number of similar concepts. Reproducibility or repeatability refers to the extent to which a pedometer is free of measurement error.<sup>19</sup> This covers both intra-instrument reliability, which is the test-retest reliability of a pedometer, and inter-instrument reliability, which refers to the variability between pedometers.

### **Feasibility**

This refers to the cost involved and skill required when using a pedometer. Feasibility also includes acceptability, the tolerance of the device and amount of lost or missing data as a result of malfunctioning and any other limitations involved. Feasibility also covers the issue of reactivity, a change in normal behaviour as a result of having to wear a pedometer.<sup>20</sup> True reactivity can only be gauged by knowingly and covertly measuring activity and comparing. Given this is practically unfeasible, most studies investigate the difference between the first and subsequent days of activity measurement.

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## Results

### Search strategy

The initial electronic search using the three main keywords, including variations led to the identification of 178 possible papers. Upon applying the inclusion and exclusion criteria as stated in the methodology, 38 articles remained. Fifteen papers were duplicates. Finally, upon reading through all of these papers and checking their bibliographies for other relevant papers, 25 papers were deemed suitable for this literature review and these are summarized in Table 1 below.

Across the 25 studies reviewed here, a total of 13 692 children and adolescents were included as subjects. They ranged from 4 to 20 years of age.

### Criterion validity

Twelve studies investigated the criterion validity of pedometers by comparing their performance to that of direct observation.<sup>21–33</sup>

Beets *et al.*<sup>21</sup> compared the accuracy of four different types of pedometers to direct observation by looking at the two across five speed grades and for all four pedometer brands used, the accuracy improves with increasing speed (ICC = 0.225–0.99). When asked to walk at a normal pace, no longer on the treadmill, subjects walked at  $\sim 67 \text{ m} \cdot \text{min}^{-1}$ , the third of five paces. Duncan *et al.*<sup>27</sup> presented similar findings, pedometers performing well at moderate and fast paces (0.7% measurement error) but underperformed at slower walking speeds (20% measurement error). Mitre *et al.*<sup>23</sup> recorded a correlation between the pedometer-determined activity and directly observed activity ranging from 50% accurate to 75% accurate, improving with treadmill speed in all cases.

In a free-living environment, the correlation between pedometers and direct observation ranged from  $r = 0.8$ <sup>29</sup> to ICC = 0.985<sup>21</sup> depending on the specific environment and activity that subjects were engaged in. In three studies carried out by Scruggs *et al.*<sup>26,31,33</sup> correlation coefficients with direct observation in a free-living environment ranged from 0.74 to 0.92. By investigating free-living physical activity as determined by a pedometer, Oliver *et al.*<sup>25</sup> found that it correlated poorly with direct observation. As a result, they do not recommend pedometers as an accurate measure of physical activity in children. McDonald *et al.*<sup>22</sup> found pedometers to be 99.87% accurate when compared with 10 min of self-paced walking. Kilanowski *et al.*<sup>29</sup> investigated the validity of pedometers in both a classroom and recreational setting. The findings showed a high correlation with direct observation in both instances— $r = 0.8$  (classroom),  $r = 0.96$  (recreation).

**Table 1** Studies investigating the validity and reliability of pedometers.

Reference	Study sample (n, age)	Methods	Results
Barfield <i>et al.</i> <sup>42</sup>	71	5 days in-school activity—two pedometers (Yamax SW200) on hips	Inter-instrument reliability: ICC = 0.96–0.99
Beets <i>et al.</i> <sup>21</sup>	20, (5–11)	Three laps walking—two pedometers (Yamax SW200, Walk4life LS2505) versus direct observation	Walking: Validity versus d/o: ICC ≥ 0.985 Bilateral variability: ICC ≥ 0.33–0.99 with increasing speed
		5 speeds on treadmill—four pedometers versus direct observation	Treadmill: Validity versus d/o: ICC ≥ 0.225–0.99 with increasing speed
Beets <i>et al.</i> <sup>44</sup>	141, (8–10)	7 days activity—pedometer (Walk4life LS2505) versus self-report questionnaire	Reactivity: 78.5% of children noted reactivity, 47.3% of parents
Cardon and De Bourdeaudhuij <sup>40</sup>	92, (6–12)	6 days activity—pedometer (Yamax SW200) versus questionnaire	Validity: <i>r</i> = 0.39
Craig <i>et al.</i> <sup>43</sup>	10 275, (5–19)	7 days activity—pedometer (Yamax SW200)	No reactivity between Day 1 and 2 1 day provided reliability (ICC = 0.79) and validity (absolute % error = 2.5%)
Duncan <i>et al.</i> <sup>27</sup>	85, (8–11)	3 speeds on treadmill—two pedometers (NL 2000) versus direct observation	Error versus d/o: 20–0.7% improves with increasing speed
Eston <i>et al.</i> <sup>34</sup>	30, (8–11)	4 speeds on treadmill and play—one pedometer (Yamax SW200), two triaxial accelerometers, HR monitor	Validity versus HR: Treadmill: ICC ≥ 0.816 Play: ICC ≥ 0.883
Graser <i>et al.</i> <sup>28</sup>	77, (10–12)	2 phases on treadmill (with and without belt), shake test—five pedometers (Walk4life LS2505)	Accuracy: 99% Right side deemed best position
Jago <i>et al.</i> <sup>35</sup>	78, (11–15)	3 speeds on treadmill—three pedometers (Yamax SW200), uniaxial accelerometer	Reliability: ICC ≥ 0.51–0.92 Bilateral variability: ICC ≥ 0.73–0.8
Kilanowski <i>et al.</i> <sup>29</sup>	10, (7–12)	Recreation and classroom—pedometer (Yamax SW200), triaxial accelerometer, d/o	Validity versus accelerometer: <i>r</i> = 0.6 Validity versus accelerometer: <i>r</i> = 0.99/0.5 for rec/class
McDonald <i>et al.</i> <sup>22</sup>	97, (6–20)	3 days activity/treadmill—one HR monitor, one pedometer (Stepwatch 2)/direct observation	Validity versus d/o: <i>r</i> = 0.96/0.8 for rec/class Validity versus HR: <i>r</i> = 0.49 Validity versus d/o: 99.7% accurate

Michaud <i>et al.</i> <sup>38</sup>	233, (11–15)	7 days activity—pedometer (Pedoboy), self-report	Validity versus self-report: $r = 0.15$
Mitre <i>et al.</i> <sup>23</sup>	27, (11)	4 speeds on treadmill—four pedometers (Yamax SW200), two accelerometers, direct observation	Validity versus d/o: 50–75% accurate, improving with increasing speed
Nakae <i>et al.</i> <sup>24</sup>	394, (7–12)	3 speeds on treadmill—pedometer (Kenz Lifecorder, Omron HJ7001T), direct observation	Validity versus d/o: Significant measurement error for pedometers
Oliver <i>et al.</i> <sup>25</sup>	13, (4)	Free play—pedometer (Yamax SW200), direct observation	Validity versus d/o: Significant measurement error for pedometers
Ozdoba <i>et al.</i> <sup>20</sup>	45, (9–10)	3-speed walking—pedometer, direct observation	Reliability: ICC = 0.86–0.91 (sealed) and 0.85–0.91 (unsealed)—no reactivity
Ramirez-Marrero <i>et al.</i> <sup>37</sup>	12	4 days activity on 2 occasions—sealed versus unsealed pedometer (Yamax SW200)	Validity versus accelerometer: $r = 0.88$
Rowe <i>et al.</i> <sup>45</sup>	299, (10–14)	7 days of activity—pedometer (Yamax SW200), triaxial accelerometer, questionnaire and doubly labelled water	Validity versus DLW: $r = 0.67$
Rowe <i>et al.</i> <sup>41</sup>	296, (11–13)	6 days activity—self-report questionnaire versus pedometer (Yamax SW200)	Reliability: $r = 0.69–0.79$ —no reactivity
Scruggs <i>et al.</i> <sup>26</sup>	288, (11–13)	PE class—pedometer (Yamax SW701, Walk4life LS2505) versus direct observation	Validity: $r = 0.17$ —ped provided external validity
Scruggs <i>et al.</i> <sup>33</sup>	257	PE class—pedometer (Yamax SW651) versus direct observation	Pedometer validity versus d/o: $r = 0.85–0.98$
Scruggs <i>et al.</i> <sup>31</sup>	369, (7–8)	PE class—pedometer (Yamax SW200) versus direct observation	Accuracy: 98%
Strycker <i>et al.</i> <sup>39</sup>	367, (10–14)	7 days activity—pedometer (Yamax SW701), self-report	Validity versus d/o: $r = 0.84$
Treuth <i>et al.</i> <sup>36</sup>	68, (8–9)	4 days activity—uniaxial accelerometer, pedometer (Yamax SW200), two self-report	Validity versus d/o: $r = 0.74–0.86$
Weston <i>et al.</i> <sup>32</sup>	48, (12–14)	1 day recall versus pedometer and uniaxial accelerometer	Validity versus self-report: $r = 0.04$ (at school), 0.15 (non-school), 0.25 (vigorous PA)
			Reliability: ICC $\geq 0.08$
			Validity versus accelerometer: $r = 0.47$
			Validity: $r = 0.88$ , pedometer provided external validity

## Convergent validity

Three studies measured the convergent validity of pedometers against heart-rate monitors.<sup>22,32,34</sup> Six studies measured the convergent validity of pedometers against accelerometers<sup>29,32,34–37</sup> and five studies measured the validity of pedometers against self-report measures.<sup>36,38–41</sup>

The level of correlation between pedometers and accelerometers ranged from 0.47<sup>36</sup> to 0.99<sup>29</sup> depending on environment and type of activity. Kilanowski *et al.*<sup>29</sup> carried out testing in both a classroom and recreational setting, and found that pedometers and accelerometers were more strongly correlated in the recreational setting ( $r = 0.98$ ) than in the classroom environment ( $r = 0.5$ ), but combined results showed an even stronger correlation ( $r = 0.99$ ). Jago *et al.*<sup>35</sup> measured only moderate and vigorous activity levels when comparing the accuracy of pedometers and accelerometers. In doing so, the author found a positive correlation between both methods ( $r = 0.6$ ), regardless of whether subjects were walking, walking fast or running.

Correlations with heart-rate monitors ranged from  $r = 0.49$ <sup>22</sup> to  $ICC \geq 0.83$ , again dependant on environment (treadmill versus free living) and activity type. Eston *et al.*<sup>34</sup> also compared the accuracy of pedometers with heart-rate monitors and correlations were established from treadmill activity and unregulated play activity. A stronger correlation was found during unregulated play ( $r = 0.883, 0.865, 0.762$ ) than during treadmill activity ( $r = 0.816, 0.712, 0.319$ ). The study also found that, along with the HR monitor, the pedometer was strongly correlated with  $SVO_2$ . McDonald *et al.*<sup>22</sup> also concluded that a pedometer was a valid method of physical activity assessment in children, based on a moderate correlation between pedometers and HR monitors ( $r = 0.49$ ).

Correlations between pedometer-determined activity and activity levels as determined by self-report and questionnaire ranged from  $r = 0.04$ <sup>39</sup> to 0.39.<sup>40</sup> One study found a correlation between pedometers and the doubly labelled water method of  $r = 0.88$ .<sup>37</sup>

## Reliability

The inter- and intra-unit reliability as well as inter-brand reliability of pedometers was investigated in eight of the studies.<sup>21,23,28,34–36,42,43</sup>

Barfield *et al.*<sup>42</sup>, Beets *et al.*<sup>21</sup> and Jago *et al.*<sup>35</sup> looked at reliability of pedometers with specific reference to bilateral variability—right versus left placement. Beets *et al.*<sup>21</sup> did so using four different brands of pedometer and at five different speeds. Bilateral variability travelled in range from  $ICC \geq 0.33$  to 0.99 depending on activity and speed of



movement, increasing with speed. During walking, walking fast and running tests, Jago *et al.*<sup>35</sup> had subjects wear three identical pedometers around their waists. Jago *et al.* found that the degree of reliability among pedometers ranged from ICC  $\geq 0.51$  to 0.92 and inter-unit reliability levels ranged from 0.73 to 0.8.<sup>35</sup> Once again, this variance in range was due to type of activity, fast walking deemed more reliable than running. Barfield *et al.*<sup>42</sup> recorded a very small range in reliability (ICC = 0.96–0.99), regardless of the setting.

Graser *et al.*<sup>28</sup> had subjects wear five pedometers at once, three around the waist and two on the thigh. Mean percentage error at each site was established by direct observation. The right side of the waist was deemed the site with the lowest rate of pedometer inaccuracy (5.3%). Mitre *et al.*<sup>23</sup> and Eston *et al.*<sup>34</sup> also experimented by using more than one pedometer at a time. Mitre *et al.*<sup>23</sup> discovered a variation of between 3 and 10% depending on what side of the body the pedometer was worn. Both studies concluded that the use of just one pedometer, worn on the right side of the hip, was sufficient to give a valid reading of a child's physical activity levels.

## Feasibility

The feasibility of pedometers, specifically looking at reactivity, was assessed in three studies.<sup>20,43–45</sup> Ozdoba *et al.*<sup>20</sup>, Craig *et al.*<sup>43</sup> and Rowe *et al.*<sup>45</sup> gauged reactivity based on the hypothesis that if the observed activity on the first day(s) is not significantly different from activity levels on the last day(s), then reactivity has not taken place. In the Rowe *et al.*<sup>45</sup> study, reliability improved as the number of days increased ( $r = 0.59–0.81$ ). Ozdoba *et al.*<sup>20</sup> noted that this parameter varied from an ICC of 0.8–0.91, whereas Craig *et al.*<sup>43</sup> recorded an ICC ranging from 0.79 to 0.92. In the other study measuring reactivity, it took place for 79 and 47% of children, as observed by the child and parent, respectively.

Investigating the benefit of sealing pedometers, Ozdoba *et al.*<sup>20</sup> noted that seven unsealed pedometers had been tampered with and reset, compared with zero sealed pedometers.

## Discussion

### Criterion validity

The most suitable gold standard method of physical activity, and specifically step count measurement, is direct observation. However, accurate direct observation over the course of 1 day would require the

researcher to record every moment of a 24 h period in close proximity of the subject. This is very impractical in normal living circumstances and as a result, researchers try to find a more controlled environment to carry out observation. With this in mind, a more favourable environment for physical activity assessment by direct observation is on a treadmill. As a result, the criterion validity of different methods of physical activity assessment is often measured via a treadmill test. This review covers seven studies that assessed the validity of pedometers in this way.<sup>21–25,27,28</sup>

Beets *et al.*<sup>21</sup> and Duncan *et al.*<sup>27</sup> both noted that the accuracy of pedometers improved with increasing speed. Although the pedometer underestimated physical activity at a slower pace, this is an uncharacteristically slow pace for a child to walk at and not representative of their behaviour in free-living environment. Duncan *et al.*<sup>27</sup> proposed that this underperformance could be explained by the mechanics of the pedometer. A force of 0.35 g is required to register a step on a pedometer.<sup>46</sup> Given that, at the slower paces, children are more inclined to take long, slow and controlled steps, they may not be achieving the required g-force, a theory supported by the findings of a recent study by Duncan *et al.*<sup>27</sup> As a result, pedometers underestimate physical activity levels when compared with direct observation. Mitre *et al.*<sup>23</sup> and Nakae *et al.*<sup>24</sup> also found that decreasing speed leading to decreasing accuracy could be attributed to insufficient acceleration and displacement.

Given that the pedometers were deemed valid indicators of physical activity at moderate and fast speeds, the practical significance of the poor correlations at lower speeds may not be relevant. First, children do not travel at such a slow pace when walking. Second, it is moderate and vigorous activity that is required for children to incur health benefits, not slow walking. Therefore, it is most important that moderate and vigorous activity should be tracked by the pedometer. Despite the fact that pedometers were consistently inaccurate at the slowest speeds, the accumulated evidence suggests that they are highly reliable at more practical speeds.

However, the author does note that poor correlation may be in part due to the use of direct observation (Children's Activity Rating Scale), which was designed to measure energy expenditure, not physical activity. These are two very different variables and it is worth remembering that the sole function of a pedometer is to measure step counts, not energy expenditure. Also, the feasibility of direct observation in a free-living environment is questionable and may have affected the results.

McDonald *et al.*<sup>22</sup>, Kilanowski *et al.*<sup>29</sup> and Scruggs *et al.*<sup>33</sup> recorded high levels of criterion validity during self-paced walking, a recreational setting and PE class, respectively. The consistent accuracy of pedometer

data compared with direct observation in these and other studies,<sup>26,28,30</sup> even in a free-living environment, gives further weight to the argument that it is a valid method of activity measurement. In both recreational and more sedentary (classroom) situations, pedometers have the capacity to gauge both children's activity and inactivity, intimating that pedometers are highly representative in normal free-living conditions.

### Convergent validity

As expected, subjects were much more active in the recreational environment than in the classroom, where they would be obliged to remain seated and predominantly sedentary. It is important to understand the nature of children's behaviour in this setting—short bursts of high levels of activity combined with longer periods of low-intensity activity and sedentary behaviour.<sup>47</sup> As a result, it is understandable that the pedometer is less accurate in a classroom situation, children are mainly seated and little vertical movement takes place. This means that the pedometer does not record any g-force. With this in mind, the author suggests that pedometers are an accurate method of determining moderate to vigorous activity, but not lower intensity activity. It is this sort of moderate and vigorous activity that is most important to track and promote in children and adolescents.

Treuth *et al.*<sup>36</sup> found pedometer-determined activity to be only moderately correlated with accelerometers following a 4-day testing period. The pedometer used in this study required the subject to record their total step counts on a daily basis, and a lack of cooperation may explain the poorer association. The majority of pedometers now have the capacity to store the daily step count over a number of days without any reliance on the subject to account for such limitations.

Overall, pedometers perform very favourably when compared with accelerometers. The comparative mechanical limitation of pedometers (measuring motion in one plane only) is a minor limitation, but the measurement of moderate and vigorous ambulatory motion is similar for both devices. Ramirez-Marrero *et al.*<sup>37</sup> recorded a stronger correlation between pedometers and accelerometers ( $r = 0.88$ ) than between pedometers and the doubly labelled water method ( $r = 0.67$ ). This stands to reason as the doubly labelled water method is more suited to recording energy expenditure than step counts.

The comparison of pedometers with similar methods of physical activity measurement consistently shows that pedometers are just as effective as more widely validated methods like heart-rate monitoring and accelerometry. Some concern has been voiced at the inability of pedometers to measure sedentary behaviour, and this is deemed an

advantage of accelerometry. But the studies mentioned here provide encouraging evidence of pedometers being as effective as accelerometers in a sedentary, classroom setting.

## Reliability

The accurate inter-unit agreement implied that pedometers are a reliable form of physical activity measurement and that the side of the body that the pedometer is worn is not relevant.

There were no significant differences between sites in these studies, suggesting that all were viable sites to validly establish activity levels in children. Even so, Graser *et al.*<sup>28</sup> recommended the right side of the waist as the optimum site for pedometer placement, solely because it allows the subject to read their step count. It seems that hip placement seems the most practical site for a pedometer. This ensures that ambulatory activity is recorded. Placement on the ankle or leg would cause a pedometer to record cycling and other similar movements. Although beneficial as a more accurate indication of physical activity, this would no longer solely constitute step counts. Widespread agreement and instruction on the proper placement of a pedometer remains relatively sparse, and more research is required to establish an accepted protocol across all studies. Such agreement would allow for confident comparison of results between studies.

Another important issue that needs to be considered when discussing reliability is sensitivity. This is the vertical threshold required to administer one step. Differences in sensitivity from one pedometer to the next may lead to variations in the accuracy of pedometers. For example, a CSA pedometer requires 0.3 g to register a step, whereas a YX200 pedometer requires 0.35 g, and this may explain the difference found between these two types of pedometers in a study by Tudor-Locke *et al.*<sup>15</sup> Increased sensitivity means you can record slow steps, but you also record much more non-ambulatory movement like fidgeting and twisting.

The effect of body composition, and particularly obesity, on pedometer accuracy is another important reliability issue. A pedometer should ideally be placed in the vertical plane to ensure it registers displacement from ambulatory movement.<sup>28</sup> This placement could potentially be affected by excess abdominal adiposity.<sup>15</sup> However, both Duncan *et al.*<sup>27</sup> and Abel *et al.*<sup>48</sup> failed to find a significant difference in pedometer bias according to body composition. Both studies compared step counts according to waist circumference, while Duncan *et al.*<sup>27</sup> also compared BMI and percentage body fat. Duncan *et al.*<sup>27</sup> did note that pedometer bias was significantly affected by the pedometer tilt-angle.

Although an important limitation of pedometer use, non-ambulatory movement like cycling and swimming is largely unreported in the literature. This is a significant issue that requires further research.

## Feasibility

Pedometers are cheap and easy to use for both researchers and lay people. No limitations were mentioned in any of the studies citing an inability to operate them, or complaining about large costs incurred. With this in mind, pedometers are practical for use in large studies of children's activity.

Compliance is a particularly important feasibility issue related to the use of pedometers in large-scale field studies. The largest study reviewed here, Craig *et al.*<sup>43</sup> highlighted a 97% compliance rate as one of the main achievements of the study. Elsewhere, compliance remains an under-reported but important issue. In the future, studies should include information on the rate of compliance and how this was achieved. This will allow other researchers to improve their methodology to ensure the highest possible levels of adherence in their pedometer studies and will also allow for easier comparison between studies.

Regarding reactivity, there is a concern that if someone is aware that their activity levels are being monitored, they will become more active. This may be particularly true for children and adolescents, given that they are inherently competitive. By comparing the effectiveness of sealed and unsealed pedometers, Ozdoba *et al.*<sup>20</sup> found no evidence of reactivity in either case. A significant difference occurred between days on one occasion, but given that this was probably due to the fact that it rained on this day, it was not deemed to represent reactivity.

Using just unsealed pedometers, both Rowe [45] and Craig [43] came to a similar conclusion. The fact that there was no significant difference in mean step counts between Day 1 and 2 intimates that children did not alter their behaviour because they were wearing pedometers. The debate about whether to seal pedometers centres in relation to that of an unsealed pedometer might promote reactivity. Both of these studies suggest that neither sealed nor unsealed pedometers are affected by reactivity among children.

As previously mentioned, the use of pedometers in a controlled clinical setting, such as on a treadmill, differs greatly from their use in a more realistic daily situation. With regard to validity, it is much easier to effectively gauge the accuracy and reliability of pedometers on a treadmill by comparing them to direct observation. This is not the case in a free-living environment, where accurate direct observation is very

difficult, if not unfeasible. Observing step counts on a treadmill simply involves the researcher counting consistently step by step. In a free-living environment, the notion of 'one step' is much more ambiguous. In a classroom, a child may be seated but moving from side to side. Playing outside, they may hop, skip, jump, sidestep, run, walk and crawl all in a short period of time. Through direct observation, it becomes very difficult to discern whether or not any or all of these motions, which do constitute physical activity, are considered the equivalent of 'one step' by the researcher or by the pedometer.

Using a pedometer in a free-living environment presents a number of other limitations. If a child is asked to walk on a treadmill for any amount of time, possible complications like defining outliers and accounting for missing data are of no concern. Usually in this type of study, subjects are only asked to walk for a few minutes, and the researcher puts on and takes off the pedometer immediately before and after testing. Given that a researcher is constantly present to monitor and instruct the subject, the pedometer should not be interfered with in any way.

In a free-living environment, children may be given a pedometer to wear for 7 days without any supervision. In this instance, children can lose, break or manipulate their pedometers. This results in missing data. If the pedometer is unsealed, children have the capacity to reset them, as observed by Ozdoba *et al.*<sup>20</sup> This is of practical importance when planning a large-scale pedometer study, as sealing pedometers, although beneficial, is often very time-consuming and may be unfeasible.

Only one study<sup>45</sup> covered the issue of outliers in any detail, proposing outliers of 1000–30 000 for children. These limits were established primarily by establishing a reasonable range for step count scores based on prior testing experiences and hypothetical situations of extremely active and inactive children. The establishment of outliers for specific populations, both children and adults, is an important and under-reported issue that needs to be explored further.

## Conclusion

A number of studies have investigated the inter- and intra-unit reliability of pedometers, as well as their criteria and convergent validity, as established through comparison with direct observation, accelerometers and heart-rate monitors. This paper reviewed these studies to establish the utility of pedometers as a determinant of physical activity among children and adolescents.

It is quite common for studies of this nature to investigate the merits of different methods by measuring physical activity levels as established by a subject walking on a treadmill. In doing so, some studies have proposed that pedometers are a valid method of physical activity measurement, particularly at moderate and fast speeds. However, children and adolescents do not do their physical activity on a treadmill. Field studies, with the validity of pedometers being assessed in free-living conditions, are a much more relevant indicator of activity levels. A number of such studies have been carried out and established that pedometers are reliable and valid measures of physical activity levels for children and adolescents.

Pedometers do have limitations, specifically with regard to the measurement of sedentary behaviour and accounting for missing data. However, this is largely accounted for by the nature of children's behaviour, short intense bursts of activity followed by longer periods of inactivity. Encouraging results also show high correlations between pedometers and both direct observation and accelerometers in low-intensity and sedentary environments. Positive levels of inter- and intra-pedometer reliability promote the effectiveness of pedometers. Given they are relatively cheap and easy to use, pedometers can potentially be used in large-scale epidemiological studies and interventions, offering motivational and educational support. This review concludes that pedometers can effectively be utilized as a valid determinant of physical activity levels among children and adolescents.

## Funding

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