

The reliability and validity of a research-grade pedometer for children and adolescents with cerebral palsy

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AIM The aim of this study was to determine the reliability, validity, and optimal placement of pedometers in children with cerebral palsy (CP) who ambulate without aids.

METHOD Seventeen participants aged 7 to 17 years with CP (eight males, nine females; mean age 12y 4mo; SD 3y 2mo), who could ambulate without aids, wore four New Lifestyles pedometers (NL-1000) on an elasticized waist belt. Fourteen participants had hemiplegia, two diplegia, and one triplegia; all were classified in Gross Motor Function Classification System (GMFCS) level I ($n=8$) or II ($n=9$). Participants completed 3-minute walking and running trials around an indoor course and were videotaped to verify the actual number of steps taken during each trial. Inter-pedometer reliability was determined by comparing pedometer readings using intraclass correlation coefficients (ICCs). Validity was determined by comparing pedometer step counts with video step counts using ICC, t -tests, and Bland–Altman plots. Optimal pedometer placement was determined using Wilcoxon signed-rank tests to compare the percentage error for pedometers positioned on the dominant and non-dominant hips.

RESULTS Excellent reliability (ICC 0.88–0.99) and validity (ICC 0.78–0.95) were demonstrated with no significant difference between the video step counts and pedometer step counts. There was no significant difference between the step counts recorded by pedometers on the dominant and non-dominant hips.

INTERPRETATION This study showed that NL-1000 pedometers have a high degree of reliability and validity in ambulant children with CP in controlled conditions.

Physical activity is defined as ‘any bodily movement produced by skeletal muscles that requires energy expenditure’,¹ and is important for the health and well-being of children,^{2,3} with benefits including improved self-esteem,⁴ improved bone health,⁵ and prevention of obesity.⁶ Such benefits have prompted the World Health Organization to recommend that children should undertake at least 60 minutes of moderate to vigorous physical activity every day.⁷ In people with physical disabilities, such as cerebral palsy (CP), there is growing evidence that regular physical activity plays an important role in the maintenance of physical function and independence.^{8–10}

Recent research suggests that children with disabilities such as CP are less physically active than their non-disabled peers,^{11,12} prompting the development of physical activity interventions specifically targeting children with physical disabilities.^{13–15} Although this field of clinical practice and research is gaining momentum, it is hindered by the lack of outcome tools validated for measurement of physical activity in children with disabilities.

Three recent systematic reviews of physical activity measurement tools for children with CP noted that subjective

tools, such as self- or proxy-reported questionnaires and interviews, have been used with this population.^{16–18} However, subjective physical activity tools typically have only weak to moderate validity.¹⁹ In studies carried out in non-disabled paediatric participants, non-invasive objective measurement tools, such as accelerometers and pedometers, are often favoured.²⁰ Accelerometers are able to capture the intensity of physical activity and the duration of a bout of activity, making them useful research tools, particularly when attempting to assess physical activity in relation to physical activity guidelines. Among children with CP, various models of accelerometers that have been evaluated include the StepWatch,²¹ the Minimod,²² the Activity Monitoring Pad-331,²² the Intelligent Device for Energy Expenditure and Activity,²³ and the Actigraph 7164.^{24,25} These devices typically showed a high level of accuracy when detecting continuous walking in children with CP (e.g. $r=0.72$ – 0.97 for the StepWatch, the Minimod, the Activity Monitoring Pad-331, the Intelligent Device for Energy Expenditure and Activity;¹⁶ $r=0.75$ for the Actigraph 7164²⁵) but lower validity for free play (Actigraph $r=0.67$ relative to direct observation²⁵) and stair

climbing (Minimod 63–81% error;²² Activity Monitoring Pad 15% error²²). However, accelerometers are relatively expensive (typically several hundred dollars per unit), require specialized software, have limited battery life (approximately 1–3wks), and do not provide immediate feedback to participants. For these reasons, they are most often used in funded research studies. In contrast, pedometers are relatively simple devices which capture the volume of ambulatory activity (but not intensity or duration of activity bouts). They are low cost, have a long battery life (typically several months), are easy to use, and provide feedback, making them feasible for use in both clinical and research settings to measure objectively or intervene in physical activity.²⁶

To date, no study has scrutinized the reliability and validity of pedometers for use with children with CP. In addition, the optimal placement of the pedometer on the waist is currently unclear. In the literature relating to non-disabled populations, pedometers are conventionally worn on the dominant side of the body, although some manufacturers recommend wearing them on the right side, regardless of the side of dominance. However, given that CP and other physical disabilities can involve considerable asymmetry of movement, it is possible that pedometer accuracy may vary depending on which side of the waist it is worn. A recent systematic review of the literature regarding the reliability and validity of pedometers in adults and children with physical disabilities²⁷ found inconsistent evidence: Beets et al.²⁸ reported that placement over the right hip was superior to placement over the left hip whereas Dijkstra et al.²⁹ reported the opposite and Manns et al.³⁰ found no difference between side of placement. Interestingly, all three studies framed the research question in terms of right versus left side, without considering participants' handedness or side of impairment. Thus, it is possible that the discrepancies in findings between studies may have been a result of differences in the relative proportions of left-handed and right-handed individuals or the relative proportions of participants with left-sided or right-sided impairment in the study samples.

In order to address these gaps in the literature we conducted a study which aimed to determine (1) the criterion validity of a high-quality, research-grade pedometer, (2) the interdevice reliability, and (3) the optimal placement of the pedometers on the waist, in children with CP.

METHOD

Participants

A convenience sample of participants was recruited from Novita Children's Services, Adelaide, the sole provider of therapy services for children with physical disabilities in South Australia. Clients were eligible to participate if they (1) had CP, (2) were aged 7 to 17 years, (3) were classified in Gross Motor Function Classification System (GMFCS) level I or II,³¹ (4) lived in Adelaide, Australia, and (5) attended a mainstream school. Recent orthopaedic surgery impacting on a participant's mobility was an exclusion criterion. A

What this paper adds

- A high-quality pedometer (the NL-1000) is highly reliable and valid in children with CP in a controlled setting.

priori power analyses showed that, for the validity component of the study, 11 to 17 participants were required to detect intraclass correlation coefficients (ICCs) of 0.6 or greater with a power of 80%. For the reliability component, a sample size of 17 would detect an ICC of 0.8 with a power greater than 99%. Therefore, the target sample size was 17. Potential participants were sent an invitation letter, with non-responders receiving a follow-up invitation.

Equipment

The NL-1000 (New Lifestyles Inc, Lees Summit, MO, USA) is an advanced pedometer, containing an internal clock, allowing it to collect daily total steps and daily total distance for 7 days without needing to be reset. It also has some additional properties normally restricted to accelerometers, allowing it to estimate total daily minutes of moderate to vigorous physical activity. It is considered to be among the highest quality, research-grade pedometers available and has been demonstrated to have validity superior to that of the highly regarded Yamax DWSW-200 and Walk4Life W4L Duo pedometers, and similar to that of the Omron HJ-151 pedometer, in adult populations without disabilities.³²

Procedure

Participants attended a single appointment at Novita Children's Services, at which they were fitted with four pedometers on an elasticized belt, two on the right side (R1, R2) and two on the left side (L1, L2; Fig. 1), in line with the midline of the thigh.³³

Participants walked for 3 minutes around a 20m figure-8-shaped track. Step count readings from the four pedometers were taken immediately before starting and immediately after the trial (this was done because NL-1000 pedometers measure total daily step counts from midnight to midnight, and cannot be manually zeroed during the day).

Participants were filmed using a tripod-mounted, high-definition digital video camera (2009 FlipVideo UltraHD Camcorder; Cisco, San Francisco, CA, USA).

After a 10-minute rest, participants repeated the trial at a self-selected running pace (brisk walking was permissible if participants were unable to maintain running).

Demographic data (date of birth, sex, distribution of impairment, side of dominance, use of ankle-foot orthoses, and parent-reported GMFCS level) were obtained via a written questionnaire.

Data treatment

Pedometer step counts for each of the pedometers (R1, R2, L1, and L2) for each walking and running trial were calculated by subtracting before-trial readings from after-trial readings. To account for the participants' side of dominance, the pedometer step counts (R1, R2, L1, and

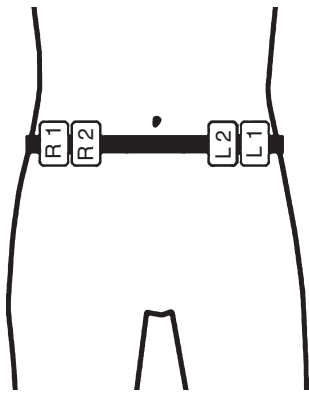


Figure 1: Placement of four pedometers on the body.

L2) were reclassified as dominant or non-dominant counts (D1, D2, ND1, and ND2) on the basis of their reported side of dominance.

The actual number of steps (actual step counts) taken in each trial was determined by one of the investigators (AK), who viewed the video footage of each trial and manually counted the number of steps taken. Video footage was viewed using VLC media player software (Version 4.4.4; VideoLAN, Paris, France) at 50% speed. A pilot study was undertaken to determine the inter- and intrarater reliability of this procedure. Intrarater reliability was assessed by one of the authors (AK) viewing video footage for five randomly selected participants on two separate occasions, 7 days apart, and was shown to be highly reliable (ICC>0.99) for both the walking and the running trials. Interrater reliability was determined by comparing step counts when two researchers (AK and CM) independently viewed video footage of five randomly selected participants. There was high reliability (ICC>0.99) for both the walking and the running trials.

Percentage error was calculated: (pedometer step counts minus actual step counts)/actual step counts × 100. Absolute percentage error was used (i.e. negative values were converted to positive values) to prevent mean percentage error being underestimated.

Data analysis

Participants' demographic data were analysed descriptively. Analyses were conducted in SPSS Statistics for Windows, version 17.0 (IBM SPSS Statistics, IBM Corp. NY, USA).

Interpedometer reliability was determined by comparing the pedometer step counts recorded by the two pedometers on the same side of the body during the walking and running trials using ICC (calculated in SPSS Statistics using the ICC [direct] via scale/reliability analysis method).³⁴

Pedometer validity was determined by comparing pedometer step counts with the actual step counts using ICCs and paired *t*-tests. Bland–Altman plots were used to detect the presence of systematic error.³⁵

Optimal pedometer placement (i.e. whether the pedometer recorded steps more accurately when positioned on the dominant or non-dominant side) was determined by comparing the absolute percentage error for pedometer readings from the D1 and ND1 pedometers using the Wilcoxon signed-rank test.

Ethical approval for this quasi experimental study was granted by the University of South Australia Human Research Ethics Committee. Participants and their parents were required to give written informed consent before participation.

RESULTS

Data were collected from 17 participants (eight males, nine females; mean age 12y 4mo; SD 3y 2mo, range 7–17y) between October 2010 and February 2011. Eight participants were in GMFCS level I and nine in level II; the majority of participants (*n*=14) had hemiplegia, two had diplegia, and one triplegia (Table I).

The mean (SD) actual step counts and pedometer step counts from each of the four pedometers (D1, D2, ND1, and ND2) for the walking and running trials are summarized in Table II.

Interpedometer reliability

ICCs showed excellent reliability for both the walking (ICC 0.88–0.94) and the running trials (ICC 0.98–0.99) when step counts from pedometers positioned on the same side of the body were compared (Table II). Paired *t*-tests showed no significant difference between the pedometers on the same side for either the walking or the running trials (*p*=0.44 [D1 vs D2 walk]; *p*=0.12 [ND1 vs ND2 walk]; *p*=0.25 [D1 vs D2 run]; *p*=0.71 [ND1 vs ND2 run]).

Given the high reliability of two pedometers placed on the same side of the body, the analyses for validity used data from only one pedometer placed on the dominant side (D1) and one pedometer placed on the non-dominant side of the body (ND1).

Table I: Participant characteristics

Characteristic	<i>n</i>	Mean (SD)
Sex		
Male	8	
Female	9	
Age (y:mo)		12:3 (3:2)
GMFCS level		
I	8	
II	9	
Dominance		
Left	10	
Right	7	
Use of ankle–foot orthosis during testing		
Yes	4	
No	13	
Distribution of impairment		
Hemiplegia	14	
Diplegia	2	
Triplegia	1	

GMFCS, Gross Motor Function Classification System.

Table II: Actual step count and pedometer step count data, reliability, validity, and percentage error

	Mean (SD)		Reliability: ICC (95% CI)		Validity: ICC (95% CI)		Percentage error (SD)	
	Walking trial	Running trial	Walking trial	Running trial	Walking trial	Running trial	Walking trial	Running trial
Actual step counts	37 (30.9)	51 (42.4)						
D1	36 (32.3)	512 (39.9)	D1 vs D2, 0.88 (0.71–0.96)	D1 vs D2, 0.98 (0.94–0.99)	D1 vs actual steps, 0.94 (0.83–0.98)	D1 vs actual steps, 0.94 (0.84–0.98)	1.8 (2.6)	1.7 (2.5)
D2	365 (40.6)	509 (44.2)						
ND1	371 (36.8)	508 (51.4)	ND1 vs ND2, 0.94 (0.84–0.98)	ND1 vs ND2, 0.99 (0.96–1.00)	ND1 vs actual steps, 0.78 (0.49–0.92)	ND1 vs actual steps, 0.95 (0.87–0.98)	3.3 (5.4)	1.7 (3.0)
ND2	366 (39.5)	508 (44.5)						

ICC, intraclass correlation coefficient; CI, confidence interval; D, dominant; ND, non-dominant.

Pedometer validity

For pedometer validity for the walking-paced trials, a strong correlation (ICC 0.94) was found between the D1 pedometer step counts and actual step counts, with a slightly weaker, but still excellent, correlation (ICC 0.78) for the non-dominant pedometer (ND1; Table II). Trials conducted at running speed showed excellent correlation between the pedometer readings and actual step counts for both the dominant and the non-dominant pedometers (ICC 0.94–0.95). Paired *t*-tests showed no significant difference between the pedometer step counts and actual step counts for either the walking or the running trials ($p=0.21$ [D1 vs actual walk]; $p=0.85$ [ND1 vs actual walk]; $p=0.87$ [D1 vs actual run]; $p=0.33$ [ND1 vs actual run]).

Bland–Altman analyses (Fig. 2) revealed a small systematic error ranging from a mean of -0.6 to -3.6 steps across walking and running trials. In all cases, the mean bias was negative, indicating a tendency for the pedometers to slightly undercount steps. In three of the four instances, the 95% confidence intervals suggested that the pedometer step counts were within approximately 25 to 30 steps of the actual step counts (D1 walk, D1 run, and ND1 run trials). In one instance (ND walking trial), the 95% confidence interval was much wider (44 to -46) because of two outliers.

Optimal pedometer location – dominant versus non-dominant

The validity of pedometer readings was compared for pedometers positioned on the dominant side (D1) and the non-dominant side (ND1). As already noted, the ICC values for D1 pedometer step counts compared with actual step counts appeared higher (ICC 0.94) than for the ND1 pedometer step counts (ICC 0.78) for the walking trial. However, Wilcoxon signed-rank tests for the percentage error of D1 versus ND1 showed no significant difference in the degree of error between sides. For the running trial, the ICC values were almost identical for the pedometers placed on the dominant and

non-dominant sides, and Wilcoxon signed-rank tests of the percentage error (D1 vs ND1) showed no significant difference between sides.

DISCUSSION

This study found that the NL-1000 pedometer had excellent validity and reliability for both self-paced walking and self-paced running in a controlled setting in children with CP who ambulate without aids. The side of the waist on which the pedometer was placed did not significantly affect validity.

Compared with other studies that had examined the validity of pedometers in various populations with physical disabilities, the validity of the pedometers in the current study was slightly higher (e.g. ICC 0.78–0.98 in the current study vs 0.52–0.87²⁷). One explanation for this is that there are real differences in the validity of pedometers among different physical disability populations, perhaps because of variations in gait patterns between disability groups. Alternatively, the slightly higher validity found in the current study may be a result of methodological differences. For example, the current study used the NL-1000 pedometer, which has been shown to have superior validity to other recognized, research-grade pedometers in adults without disability (namely the Yamax SW-200 and Walk4-Life Pro).³² Conversely, compared with studies which have examined the validity of pedometers in children without disabilities, the validity coefficients achieved in the current study were slightly lower (e.g. ICC 0.78–0.98 in the current study vs 0.93–0.99³⁶). Again, it is unclear whether this is a result of true differences in the validity between children with and without disability, or whether it is a result of methodological differences between the studies. Beets et al.³⁶ examined the validity of treadmill walking at a predetermined pace, while the current study examined overground walking and running involving frequent (figure-8) turns at a self-selected pace.

Bland–Altman analyses revealed a slight tendency for the pedometers to undercount steps, but the degree of error was very small, and therefore unlikely to be of importance

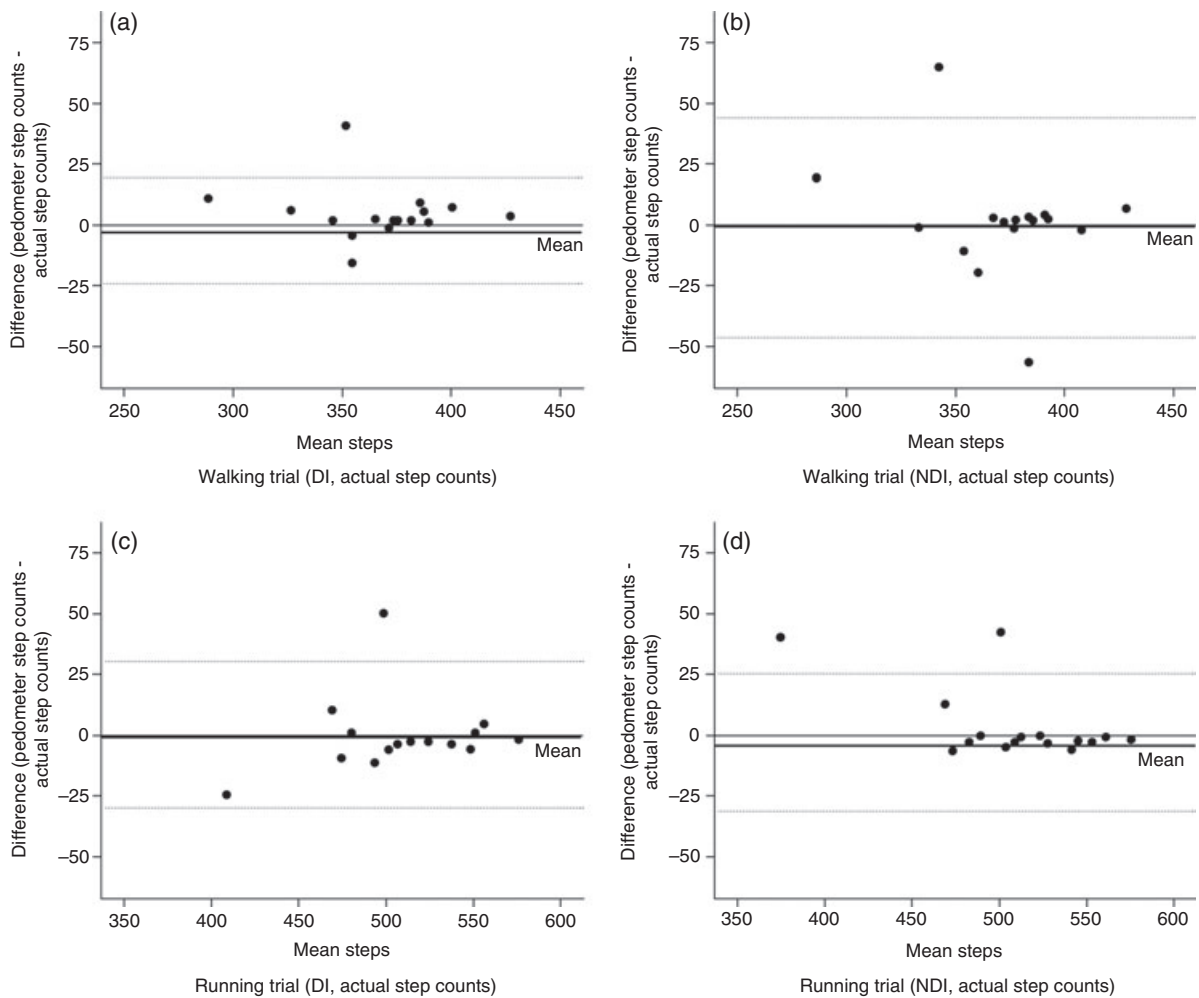


Figure 2: Bland–Altman plots for pedometer validity. The difference between the pedometer step count and the actual step count is shown on the Y-axis. The heavy black line labelled mean shows the mean of the differences (also known as the bias). The dotted lines show the 95% confidence intervals.

in most clinical or research settings. Both reliability and validity decreased slightly at slower speeds, which is consistent with pedometer studies undertaken with non-disabled populations.^{36,37}

Strengths and limitations

The strengths of this study included the use of high-quality piezoelectric pedometers and a figure-8-shaped track, meaning that turning direction alternated throughout the trials, reducing the risk of bias.³⁸ Validity and reliability were examined at both walking and running speeds, which is important, given that children typically alter their speed of locomotion throughout the day. Furthermore, the use of video recording and slow-motion replay enhanced the accuracy of the counting of actual step counts, as evidenced by the near perfect inter- and intrarater reliability.

However, a number of limitations must also be acknowledged. Only one model of pedometer (NL-1000) was

tested; thus, findings cannot be generalized to other pedometer models. Although the sample size was adequate to ensure statistical power for the research questions, it was insufficient to allow robust subgroup analyses. Certainly, descriptive analysis of the percentage error scores suggested that pedometer validity may be reduced as severity of impairment increases (e.g. mean percentage error 1.1% at GMFCS level 1 vs 2 3.1% at GMFCS level). Similarly, it appears that validity may be lower for children with involvement of both lower limbs (di- or triplegia; mean percentage error 6.7%) compared with involvement of one lower limb (hemiplegia; mean percentage error 1.2%). Further research to confirm these relationships would be valuable. Furthermore, as occurs in the majority of studies scrutinizing the reliability and validity of pedometers, the current study was conducted under controlled conditions. Pedometers have previously shown higher validity in controlled conditions than in free-living conditions.³⁹

Clinical implications

Pedometers are inexpensive and convenient tools for measuring ambulatory physical activity. They may be used for research or clinical purposes to measure or intervene on physical activity levels. The findings in this study offer preliminary evidence that the NL-1000 pedometer is a valid and reliable tool for the objective measurement of ambulatory physical activity in children with CP who ambulate without aids.

The validity of the NL-1000 in children with CP was not significantly affected by placement on either the dominant or the non-dominant hip. Given this, we would advocate following the manufacturer's instructions, which state that the pedometer should be worn on the front of the dominant hip (i.e. the least-impaired side, in the case of asymmetrical CP). However, if for some reason this is not possible, the pedometer can be placed on the non-dominant side with confidence that it will maintain validity in children with CP who ambulate without aids.

Whilst the overall validity and reliability of the pedometers were excellent, larger errors were evident for some individuals, providing preliminary indications that validity

may be affected by the severity and distribution of impairment. Clinicians and researchers should also be aware of pedometers' limitations, such as their inability to accurately capture particular types of physical activity, such as riding a bicycle and stair climbing.²⁰

CONCLUSION

This study has demonstrated that the NL-1000 pedometer has a high level of criterion validity and inter-pedometer reliability when used in children with CP who ambulate without aids in controlled conditions. Reliability and validity increase with increasing speed of movement. Placement of the pedometer on the dominant hip is recommended; however, it may be placed on the non-dominant hip if this is impractical.

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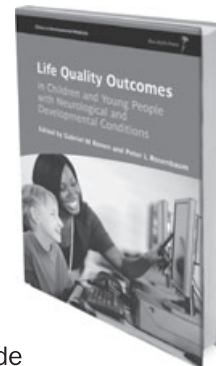
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