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Detection of walking periods and number of steps in older adults and patients with Parkinson's disease: accuracy of a pedometer and an accelerometry-based method

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Abstract

The aim of this study was to examine if walking periods and number of steps can accurately be detected by a single small body-fixed device in older adults and patients with Parkinson's disease (PD). Results of an accelerometry-based method (DynaPort MicroMod) and a pedometer (Yamax Digi-Walker SW-200) worn on each hip were evaluated against video observation. Twenty older adults and 32 PD patients walked straight-line trajectories at different speeds, of different lengths and while doing secondary tasks in an indoor hallway. Accuracy of the instruments was expressed as absolute percentage error (older adults versus PD patients). Based on the video observation, a total of 236.8 min of gait duration and 24,713 steps were assessed. The DynaPort method predominantly overestimated gait duration (10.7 versus 11.1%) and underestimated the number of steps (7.4 versus 6.9%). Accuracy decreased significantly as walking distance decreased. Number of steps were also mainly underestimated by the pedometers, the left Yamax (6.8 versus 11.1%) being more accurate than the right Yamax (11.1 versus 16.3%). Step counting of both pedometers was significantly less accurate for short trajectories (3 or 5 m) and as walking pace decreased. It is concluded that the Yamax pedometer can be reliably used for this study population when walking at sufficiently high gait speeds (>1.0 m/s). The accelerometry-based method is less speed-dependent and proved to be more appropriate in the PD patients for walking trajectories of 5 m or more.

Keywords: *older adults, Parkinson's disease, gait, accelerometry, pedometer, elderly*

Introduction

The ability to walk independently is an important determinant for daily functioning and quality of life. Various physical and psychological factors have a negative influence on the mobility of older adults. A reduced exercise capacity or an increased fear of falling might lead to a less active lifestyle [1]. Additionally, ageing-related neurological [e.g. Parkinson's disease (PD)] or non-neurological (e.g. osteoarthrosis) pathology frequently cause impairments in walking [2].

At present, the knowledge about the level and quality of physical activity in older people with or without mobility impairments is limited. Commonly used methods for mobility assessment have certain shortcomings for evaluation purposes [3]. For example, questionnaires and clinical rating scales are subjective and scores are dependent on the subject's cognitive functioning or the rater's level of expertise [4, 5]. Timed walk tests in a clinical setting reflect a momentary situation and are not entirely representative for walking in the community [6].

Objective, more continuous evaluation of gait is possible by ambulatory body-fixed instrumentation, such as pedometers [7], accelerometers [8] or gyroscopes [9, 10]. To be appropriate for long-term measurements in everyday environments, these devices should be practical and not interfere with normal movement behaviour. Pedometers are small, easy to use and count the number of steps. The Yamax Digi-Walker SW-200 (Yamax) is considered the most accurate electronic pedometer, but its precision decreases at slower walking speeds, making it less suitable for seniors with low physical fitness or gait abnormalities [11–15]. Compared

to pedometers, accelerometers have a higher accuracy and can also be utilised for the analysis of other movements besides gait [16]. However, accelerometers have not yet been applied outside the laboratory at a large scale [17]. Often the techniques consist of multiple instruments and sensors attached to different body parts. More sensors provide more information, but minimal instrumentation is preferable for activity monitoring in daily living [18, 19].

Recently a method has been developed comprising a single and small wireless triaxial accelerometer, the DynaPort MicroMod (DynaPort), positioned at the lower back. Previous studies have shown that gait parameters such as speed and distance can be estimated from trunk accelerations in children and healthy adults [20–22]. So far, the DynaPort system has not been examined for healthy older adults and older adults with ageing-related gait disturbances, such as observed in PD. Particularly for PD patients the type and sensitivity of the measurement technique might be relevant. In general, they walk more slowly with short shuffling steps and a lower step frequency when compared to healthy persons [23–25]. Furthermore, specific disease symptoms such as dual task interference, festination and freezing can complicate walking [26, 27].

The aim of the present study was to determine the accuracy of the DynaPort system for detecting walking periods and steps in older adults without gait impairments and subjects with PD during controlled indoor walking tasks. The results were compared to a Yamax pedometer at each hip and video observation of the actual performance.

Methods

Subjects

Twenty older adults and 32 PD patients with comparable age and gender were included. The subjects without PD were community-dwelling seniors selected from a list of persons who had participated in a similar gait study. PD patients with a confirmed diagnosis were recruited from the outpatients' departments of two local hospitals. Exclusion criteria were: impairments or diseases [e.g. orthopedic, neurological (other than PD for the patients)] that could affect gait, inability to walk multiple short distances together for half an hour and use of walking aids. All subjects gave informed consent prior to the study. The protocol was approved by the Medical Ethical Committee of the University Medical Center Groningen.

Materials

The DynaPort (McRoberts BV, The Hague, The Netherlands) contains three orthogonal orientated piezo-capacitive acceleration sensors, each measuring at a sample rate of 100 Hz. Data is stored on an SD card. The DynaPort (size 84 mm × 50 mm × 8 mm; weight 44.5 g) is placed in a belt which is strapped around the waist. It is positioned at the lower back, between and above the posterior superior iliac spines.

A Yamax (Yamasa Corporation, Tokyo, Japan; size 50 mm × 38 mm × 21 mm; weight 21 g) was attached to the belt at the left and right hips. A previous study [11] showed very close agreement between two Yamax pedometers when worn by healthy subjects on either the left or right side. However, in PD patients, motor symptoms can be distinctly asymmetrical. Before a subject was tested, the pedometers were checked while walking 10 steps at a normal pace by the test instructor (a healthy, 32-year-old adult). In all these measurements, the number of steps had been recorded accurately. A 100-step walking test was performed after completion of the study to determine measurement error [28]. Both pedometers had a deviation of 1 step from the 100 steps.

Procedure

Subjects were questioned about their health status and medical history. To the PD patients, the freezing of gait questionnaire (FOGQ) [27] was administered. Disease duration was calculated from the year when PD was officially diagnosed by a neurologist. Height, body mass and waist circumference were measured with clothes and shoes on.

The gait protocol included eight tasks performed in a defined area of an indoor hallway with an even floor. Each task consisted of walking a straight-line trajectory three times. First, subjects walked 15 m at preferred walking speed, slower than preferred and faster than preferred. Then, subjects had to walk 10, 5 and 3 m at their own pace. Finally, subjects walked 15 m again at preferred speed while doing a secondary task, respectively counting backward from 100 to 0 in steps of 5 or carrying a tray with two cups filled with water. All measurements were videotaped. The video camera was positioned approximately 2 m behind the finish line, so gait characteristics were assessed from a frontal view.

Data-analysis

A research assistant and a human movement sciences student independently observed 10 older adults and 10 PD patients to determine the inter-rater reliability for gait initiation, number of steps and gait termination. Appendix 1 (see supplementary data on www.ageing.oxfordjournals.org) describes how the gait characteristics were derived from the video observation. Intraclass correlation coefficients (ICCs; two-way random, absolute agreement) values were all >0.99. The remaining videos were scored by a single observer whose ratings have been used for evaluation.

The DynaPort data were emailed to the supplier for blinded analysis. The first 15 m trajectory was used for calibration to assess the subjects' specific gait characteristics. The threshold level for walking was determined from the absolute resultant of the three acceleration sensors. Walking periods were identified when the absolute resultant measured more than one-fifth of the resultant at the calibration trajectory. Gait duration was calculated between the onset and stop of the movement signal identified as a walking period. The number of steps with a minimum of three was detected from the peak forward acceleration values at foot contact [20–22]. Results were returned by email.

Gait characteristics as observed on video were taken as 'the gold standard'. The accuracy of the instruments was expressed as absolute percentage error: $\left|\frac{\text{video data}-\text{instrument data}}{\text{video data}}\right| \cdot 100$. The outcome variables were averaged for three trajectories. The level of agreement between the video observation and the instruments was determined by ICCs (two-way random, absolute agreement) that were classified as poor (<0.40), fair to good (0.40 to 0.74) or excellent (>0.74) agreement [29]. Effects between instruments and tasks were examined by repeated measures ANOVA using the pair-wise comparisons procedure to show where differences existed. Differences between subject groups were tested with independent *t*-tests, and effects within the PD patients for disease stage or asymmetry of symptoms by one-way ANOVA. Statistical analysis was performed in SPSS 14.0 at a significance level of $P<0.05$.

Results

There were no significant differences in subject characteristics between the two groups (Table 1). Disease duration ranged between 1 and 16 years. Mean disease duration in Hoehn and Yahr Stage I differed significantly from Stages II and III. FOGQ scores ranged between 0 and 15 points. Higher scores indicate more walking difficulties and a greater severity of freezing of gait. Mean FOGQ scores in Stage III differed significantly from Stages I and II.

The subjects did not experience interference or inconvenience of the body-fixed instrumentation. None of the patients reported to be in an 'off' phase. One patient showed freezing episodes during six trajectories. Appendix 2 (see supplementary data on www.ageing.oxfordjournals.org) presents the gait characteristics as derived from the video observation. The PD patients took significantly more steps compared to the older adults in all tasks. On average, the PD patients walked slower and consequently needed more time to finish the trajectories.

Based on the video observation, a total of 236.8 min of gait duration and 24,713 steps were assessed. The analysis of the DynaPort data overestimated total gait duration by 17.2 min (7.3%) and 1.6 min (0.7%) was underestimated. Step detection resulted in an overestimation of 38 steps (0.2%) and 1,299 steps (5.3%) had not been detected. Out of the 1,248 trajectories, the analysis failed to identify 12 trajectories as walking periods. This was 11 times the 3 m distance, and once the 5 m distance. The left Yamax overestimated 249 steps (1%) and 2,091 steps (8.5%) had not been counted. The right Yamax overestimated 148 steps (0.6%) and 3,460 steps (14%) had not been counted.

Figure 1 illustrates the correlation between the DynaPort and both pedometers compared to the video observation for number of steps. The DynaPort approached linearity for both groups with the majority of errors being small, but constant. The agreement was less strong for the pedometers with larger deviations for the PD patients compared to the older adults. Appendix 3 presents ICCs and 95% confidence intervals per task (see supplementary data on www.ageing.oxfordjournals.org).

The accuracy of the instruments expressed in absolute error percentages is given in Table 2. Gait duration estimation of the DynaPort data analysis was significantly less accurate at increasing gait speed and decreasing walking distances. The error in step detection increased significantly as walking distance decreased. In all, there were no significant group differences. The performance of the pedometers decreased significantly as walking pace decreased. Also, error percentages were significantly higher at the shorter distances (3 and 5 m) compared to the longer walking trajectories (10 and 15 m). In all, the error of the left Yamax was significantly larger for the PD patients than for the older adults. Asymmetry of the PD motor symptoms did not affect the pedometers significantly. The right Yamax recorded less accurately than the left Yamax in the majority of the tasks and in the older adults as well. Overall, mean absolute percentage error of the DynaPort was significantly smaller than the left Yamax for the PD patients and smaller than the right Yamax for both groups. Appendix 4 (see supplementary data on www.ageing.oxfordjournals.org) shows that particular right

Table 1. Subject characteristics

Characteristics	Older adults	PD patients			
Hoehn and Yahr Stage	—	I ($n=11$)	II ($n=11$)	III ($n=10$)	All
Age (year)	68.5 ± 7.4	65.4 ± 5.0	70.0 ± 8.3	66.6 ± 5.5	67.3 ± 6.6
Gender (male/female)	10/10	6/5	6/5	5/5	17/15
Height (cm)	173.5 ± 9.7	176.0 ± 10.3	172.4 ± 11.9	177.5 ± 7.3	175.2 ± 10.0
Body mass (kg)	79.7 ± 13.4	80.0 ± 15.0	85.6 ± 14.0	80.6 ± 14.6	82.1 ± 14.3
BMI (kg/m^2)	26.4 ± 2.9	25.7 ± 3.7	28.9 ± 4.4	25.4 ± 3.1	26.7 ± 4.0
Waist circumference (cm)	99.1 ± 10.6	101.7 ± 9.2	105.8 ± 10.4	102.1 ± 12.3	103.0 ± 10.4
Most affected side (left/right/equally)	—	(6/5/0)	(8/3/0)	(2/5/3)	(16/13/3)
Disease duration (year)	—	3.4 ± 1.7[a]	6.4 ± 2.2	9.2 ± 3.8	6.3 ± 3.5
FOGQ score (score 0–24)	—	3.3 ± 2.4	4.6 ± 2.9	9.7 ± 3.8[b]	5.8 ± 4.1

Values are means ± standard deviation.

[a] Significant difference from Hoehn and Yahr Stages II and III ($P<0.05$).

[b] Significant difference from Hoehn and Yahr Stages I and II ($P<0.05$).

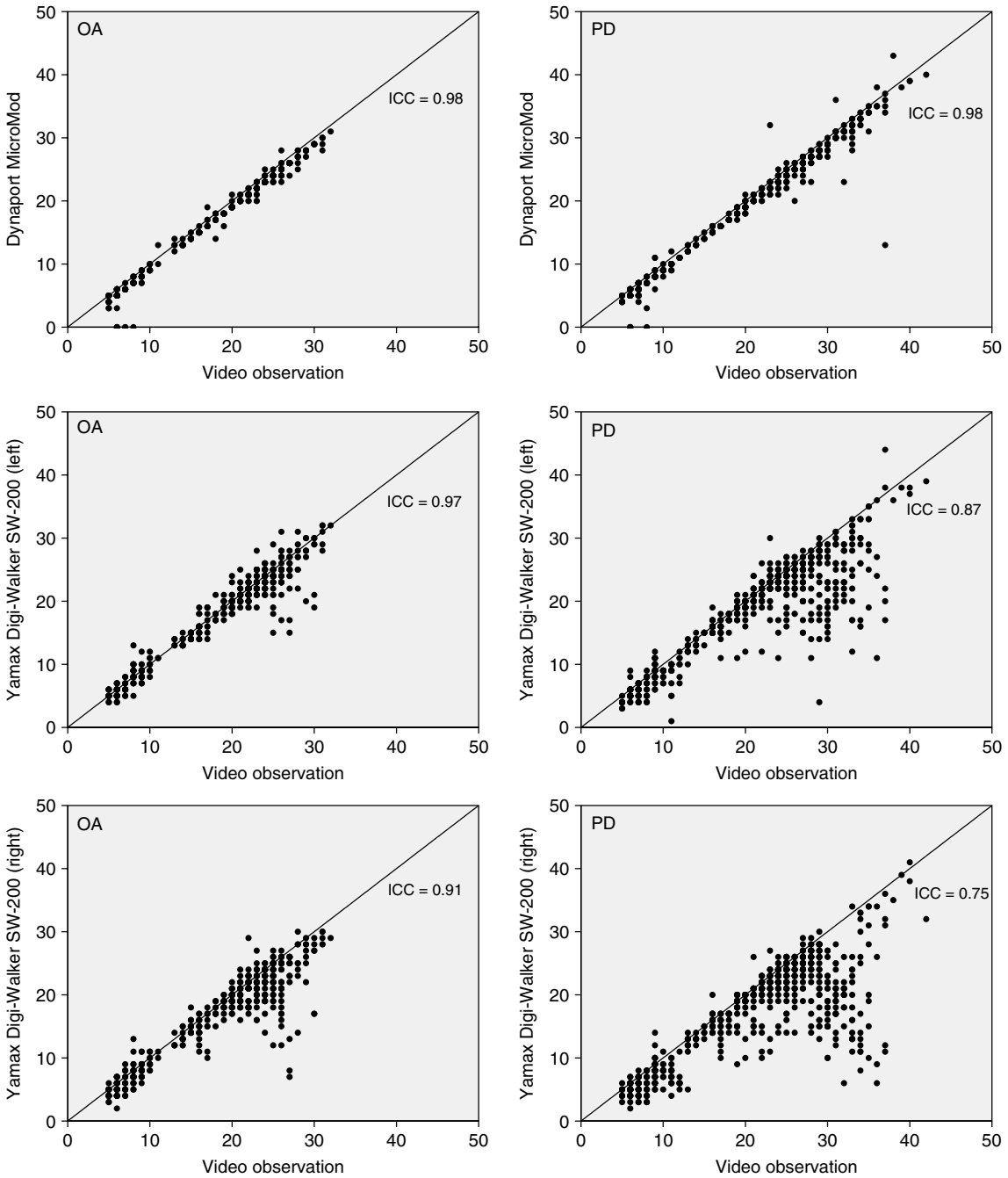

Figure 1. Number of steps counted by the DynaPort and the Yamax (left/right) compared to the video observation for the older adults (OA) and the PD patients (PD).

pedometer error increases for patients in Hoehn and Yahr Stages II and III.

Discussion

The aim of this study was to determine the accuracy of an accelerometry-based method and a pedometer to detect walking periods and steps in older adults without gait impairments and PD patients by controlled walking tasks.

The results of the DynaPort system are notably affected by missing 3-m trajectories. In these cases, six to eight steps were taken, but the absolute resultants appeared to be too small compared to the calibration trajectory. Lowering the threshold might improve the detection of short distance walks, but this could make the method also more sensitive to false classification of movements during free-living activity. An approximately 11% error in measuring gait duration was largely due to an overestimation of time. In the analysis procedure of the acceleration data, extra movement activity was included that was not part of the video definition of walking. Overall, the accuracy for step detection of

Table 2. Absolute error (%) of the instruments for the older adults (OA) and PD patients (PD)

	DynaPort duration accuracy		DynaPort step accuracy		Left Yamax step accuracy		Right Yamax step accuracy	
Task	OA	PD	OA	PD	OA	PD	OA	PD
15 m slow pace	3.2 ± 2.6 (0.9–12.1)	5.0 ± 4.4 (0.8–24.5)	4.3 ± 1.1[b] (2.7–7.1)	5.8 ± 5.0[a,b] (0–28.5)	10.2 ± 10.4[b] (2.7–38.7)	17.7 ± 17.5[b] (0–57.6)	18.0 ± 16.7 (1.1–67.6)	26.0 ± 22.7 (2.3–76.1)
15 m preferred pace	5.5 ± 1.7 (3.0–10.5)	6.5 ± 3.5 (3.2–23.5)	4.4 ± 1.7 (2.3–10.3)	3.6 ± 0.9[a,b] (1.0–5.1)	4.5 ± 2.3 (0–9.3)	8.0 ± 8.1[b] (1.3–32.3)	7.2 ± 5.9 (1.3–23.2)	12.1 ± 14.5 (0–59.3)
15 m fast pace	9.7 ± 3.7 (3.6–19.5)	9.5 ± 3.9 (3.3–22.4)	4.7 ± 0.7 (2.7–5.8)	4.0 ± 1.3 (1.3–6.0)	4.7 ± 3.2 (0–11.5)	5.6 ± 6.6 (0–35.3)	4.5 ± 2.7 (0–8.8)	9.3 ± 13.2 (1.4–54.6)
10 m	9.9 ± 3.0 (2.0–14.5)	9.9 ± 3.3 (5.1–17.6)	5.9 ± 2.2 (1.9–11.6)	5.7 ± 1.6[b] (0–7.7)	5.0 ± 3.0 (0–12.3)	7.2 ± 7.8[b] (0–42.5)	8.3 ± 7.3 (1.8–35.9)	12.4 ± 13.1 (0–52.4)
5 m	17.8 ± 9.5 (4.8–44.1)	18.3 ± 9.1 (6.7–50.3)	11.6 ± 8.1 (0–41.7)	9.6 ± 3.4[b] (0–15.2)	10.2 ± 8.0 (3.3–29.2)	13.2 ± 10.4[b] (3.7–47.5)	13.7 ± 7.8 (3.7–33.3)	20.2 ± 14.2 (0–53.9)
3 m	28.3 ± 18.2 (8.6–74.9)	28.3 ± 19.8 (3.3–100)	20.1 ± 21.0 (0–72.2)	18.4 ± 21.0 (0–100)	10.6 ± 6.6[b] (0–23.8)	17.2 ± 10.9 (0–42.9)	17.6 ± 9.7 (5.6–42.2)	22.1 ± 14.3 (0–54.2)
15 m + cognitive task	5.6 ± 2.1 (2.4–10.2)	6.2 ± 2.8 (2.1–14.1)	4.3 ± 1.6 (1.5–8.8)	4.5 ± 2.1[b] (2.1–13.2)	5.3 ± 4.1[b] (0–13.0)	9.8 ± 11.7 (0–34.6)	11.9 ± 12.8 (0–44.6)	14.0 ± 16.3 (1.4–70.6)
15 m + motor task	5.7 ± 1.7 (1.6–8.3)	5.2 ± 2.3 (0.7–9.8)	4.3 ± 0.9 (2.3–6.1)	3.4 ± 1.2[a,b] (1.0–6.1)	4.0 ± 2.4 (0–9.1)	10.0 ± 13.1 (1.3–55.1)	7.5 ± 6.4 (0–21.9)	14.5 ± 18.1 (0–74.3)
All	10.7 ± 3.4 (4.3–16.5)	11.1 ± 4.5 (5.3–23.2)	7.4 ± 3.1 (3.0–15.0)	6.9 ± 3.0[b] (2.8–16.1)	6.8 ± 2.6[b] (3.6–13.8)	11.1 ± 9.0[b] (1.0–38.7)	11.1 ± 6.6 (5.0–30.4)	16.3 ± 13.7 (2.4–53.9)

Values are means ± SD, (min. – max.).
[a] Significant difference from the left Yamax ($P<0.05$).
[b] Significant difference from the right Yamax ($P<0.05$).

the DynaPort was reasonably good in the older adults (7.4% error) and the PD patients (6.9% error). In general, differences between observed and reported steps were small, but constant and primarily (76.8%) due to an underestimation of one step. This can be explained by the closing step of a walking period, which often does not lead to a high-peak forward acceleration. The algorithm would not count it as a step, whereas it would be scored on the video because the displacement could be observed.

As in previous studies [11–15], accuracy of the pedometers was influenced by gait speed, recording fewer steps at lower velocities. This was particularly visible in the results of the PD patients, the short walking trajectories and the slow walking task. The absolute percentages error of the left Yamax ranged from 4.5 to 10% for gait speeds >1.01 m/s, and from 10.2 to 17.2% for gait speeds <0.97 m/s. At lower walking velocities, the up-and-downward movement of the spring mechanism in the pedometer is insufficient to register steps [11, 14]. The double tasks had no significant effect on the accuracy of the instruments, because both groups could maintain adequate gait speed. As expected, error percentages between the older adults and the PD patients were larger for the pedometer than the accelerometry-based method, a difference of 4.3% for the left Yamax and 0.5% for the DynaPort, respectively. A consistently higher accuracy of the left Yamax compared to the right Yamax was not a result of asymmetry of the PD symptoms. Intra-pedometer model differences have been found before and explained due to variations in spring tension [30]. It becomes evident at low walking speeds which are characteristic for this study sample.

Although several tasks with elements of everyday gait activity have been examined, further validation is needed such as long-term monitoring in the community or at home, where walking is more diverse and not limited to straight lines. Accuracy of the instruments should also be tested in PD patients with more severe gait disturbances and during 'off-phases'. It is concluded that a Yamax pedometer can be reliably used in older adults with or without gait impairments in controlled walking tests when gait speed is sufficient. However, low walking velocities are frequently associated with this study sample and the DynaPort proved to be more accurate than the pedometers in PD patients when walking 5 m or more. The DynaPort system would benefit from improved detection of very short distances like the 3 m trajectories, making it more suitable for testing in a non-laboratory setting. The DynaPort and the Yamax provide a simple and subject-friendly way to measure gait activity. Particularly, methods using a single accelerometer are limited and could be a promising technique for objective, unobtrusive and continuous evaluation of physical functioning or effects of interventions (e.g. medication, physiotherapy).

Key points

- Accelerometers and pedometers can provide an objective method for measuring gait activity.
- The use of minimal body-fixed instrumentation is necessary for long-term unobtrusive measurements in everyday environments.

- An accelerometer-based method allows for more accurate detection of step activity in patients with slower gait and smaller steps while walking straight-line trajectories of 5 m or longer.

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Conflicts of interest

There are no conflicts of interest.

Supplementary data

Supplementary data for this article are available online at http://ageing.oxfordjournals.org.

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