ORIGINAL ARTICLE

Detection of Gait and Postures Using a Miniaturized Triaxial Accelerometer-Based System: Accuracy in Patients With Mild to Moderate Parkinson's Disease

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ABSTRACT. Dijkstra B, Kamsma YP, Zijlstra W. Detection of gait and postures using a miniaturized triaxial accelerometer-based system: accuracy in patients with mild to moderate Parkinson's disease. Arch Phys Med Rehabil 2010;91:1272-7.

Objective: To examine whether gait and postures can accurately be detected with a single small body-fixed device in patients with mild to moderate Parkinson's disease (PD).

Design: Results of a triaxial accelerometer-based method were evaluated against video observation scores (criterion measure). Study 1: Subjects performed basic mobility-related activities (walking, lying, sitting, standing) in a fixed and free sequence. Study 2: Subjects were monitored while doing similar activities as in study 1 and while doing usual domestic activities.

Setting: Study 1: Standardized set-up in a movement laboratory. Study 2: Home environment.

Participants: (N=37) Study 1: Patients with PD (n=32; mean age ± SD, 67.3±6.6y; mean disease duration ± SD, 6.1±3.4y). Study 2: Patients with PD (n=5; mean age ± SD, 76.0±7.3y; mean disease duration ± SD, 3.8±4.7y).

Interventions: Not applicable.

Main Outcome Measures: The degree of correspondence between the monitor and the video observation for the duration of each activity. Overall agreement, sensitivity, specificity, and positive predictive values were calculated.

Results: Study 1: Overall agreement ranged between 69.8% and 90.8% (fixed sequence) and 57.5% and 96.9% (free sequence). Study 2: Overall agreement ranged between 60.0% and 89.2%. Lying, sitting (home), and walking were detected most accurately with mean sensitivity varying from 81.7% to 99.9%. Lower values were found for sitting (laboratory), standing, and shuffling.

Conclusions: This triaxial monitor system is a practical and valuable tool for objective, continuous evaluation of walking and postures in patients with mild to moderate PD. Detection of sitting and standing requires further fine-tuning.

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IN THE COURSE OF PARKINSON'S disease, patients' performance of basic activities like standing, walking, or rising from a chair becomes increasingly difficult.[1] Consequently, mobility may eventually deteriorate considerably to such an extent that patients become wheelchair-bound or even bedridden.[2] Current interventions including antiparkinsonian medication, surgery, or physical therapies are aimed at optimizing independent functioning and reducing motor complications.[3,4] To monitor disease progression and assess treatment effectiveness accurately, the availability of appropriate evaluation methods is required.

Frequently, self-report and observer-based instruments are used as outcome measures for mobility-related activities.[5] Yet results tend to be biased and do not provide detailed information on the actual performance in daily life. For example, interviews, questionnaires, and diaries reflect the patients' perception of physical activity status, but this could be influenced by socially desirable answers or cognitive functions like memory, which might be affected in PD.[6,7] Also, rating scale scores vary by the observer's level of expertise and are often obtained in a clinical setting at a particular moment.[8] However, movement problems of patients with PD can be context-dependent and may fluctuate over the day in response to medication.[9,10]

Objective, continuous measurements of mobility-related activities are possible by ambulatory activity monitors composed of accelerometers and gyroscopes.[11] These devices have not been applied outside the laboratory on a large scale.[12,13] Often, systems consist of a measurement unit and multiple sensors attached to different body parts.[14-22] More sensors provide more data, but minimal instrumentation is preferable for unobtrusive and long-term monitoring in everyday environments. Valid and easy-to-use single-unit activity monitors have been developed that report output in activity counts.[23,24] Although these monitors give an indication of general activity level, the ability to distinguish separate activities is essential to be able to identify specific mobility problems. Classification of basic daily activities with 1 instrument seems feasible, but such techniques are still relatively rare.[25-27]

Recently, the DynaPort MoveMonitor[a] was introduced for continuous ambulatory activity monitoring. This method is based on a single and small wireless triaxial accelerometer, the DynaPort MiniMod,[a] positioned at the lower back. In older adults without mobility impairments and patients with COPD,

List of Abbreviations

COPD	chronic obstructive pulmonary disease
PD	Parkinson's disease

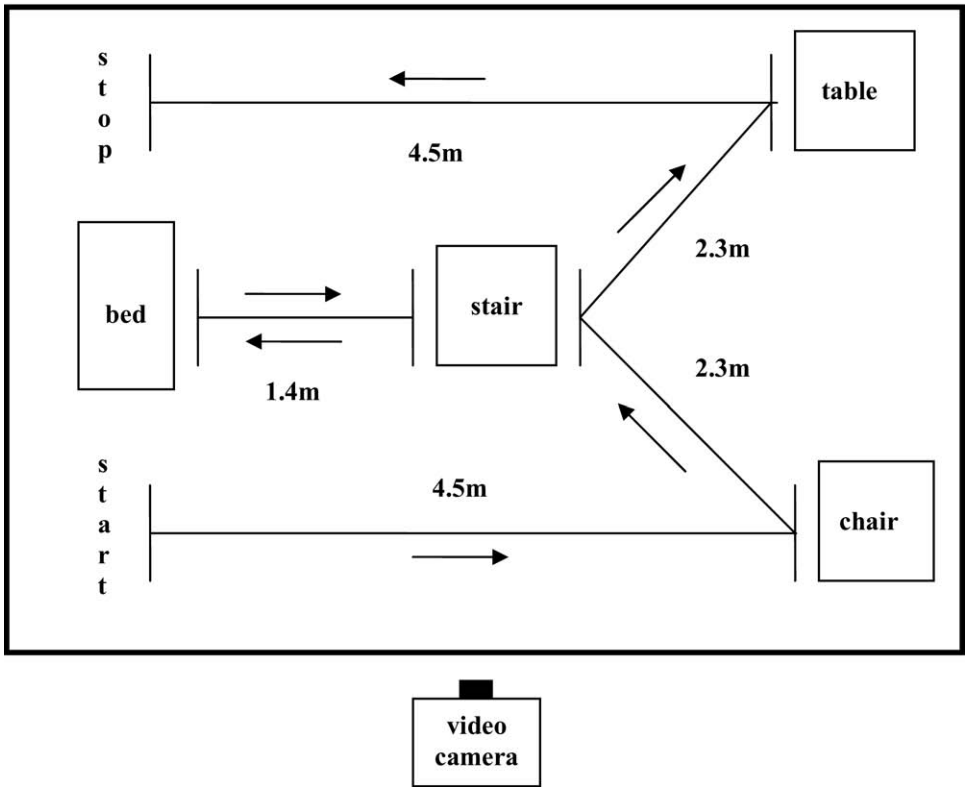

Fig 1. Set-up in the movement laboratory. From Dijkstra, et al.[28] Reprinted with permission of Oxford University Press.

it has been shown that the time spent walking and in different postures can be estimated from trunk accelerations using the MiniMod.[28,29] So far, the DynaPort MoveMonitor has not been examined in subjects with a movement disorder. Specifically in patients with PD, identification of activities from the acceleration signals may be complicated by cardinal parkinsonian motor disturbances like bradykinesia and hypokinesia.

The aim of the present study was to determine the accuracy of the DynaPort system for detecting gait (walking, shuffling) and postures (lying, sitting, standing) in patients with mild to moderate PD. Activity sequences were performed in a standardized setting (study 1) as well as in a home environment (study 2). The results were compared with video observation scores of the actual performance.

METHODS

Subjects

Thirty-two patients with PD (17 men, 15 women; mean age ± SD, 67.3±6.6y; mean disease duration ± SD, 6.1±3.4y) were included in study 1, and 5 patients with PD (4 men, 1 woman; mean age ± SD, 76.0±7.3y; mean disease duration ± SD, 3.8±4.7y) participated in study 2. Exclusion criteria were impairments or diseases other than PD (eg, orthopedic or neurologic) that could affect the performance of daily activities such as walking and getting in and out of a chair or bed. All subjects lived independently in the community and gave written informed consent prior to the study. The studies' procedures were approved by the Medical Ethical committee of the University Medical Center Groningen.

Materials

The triaxial accelerometer, the DynaPort MiniMod, contains 3 orthogonal orientated piezo-capacitive acceleration sensors, each measuring at a sample rate of 100Hz. Data are stored on a Secure Digital card. The device (84×50×8mm; weight, 44.5g) is placed in a neoprene belt strapped around the waist. It is positioned at the lower back, between and above the posterior superior iliac spines. The MiniMod was placed and ready for measurement in about 1 minute.

Procedure

Subjects answered a questionnaire concerning their health status and medical history. They were tested while on their normal medication routine. In study 1, a chair, a 3-step stair, a bed, and a table had been arranged in a movement laboratory (fig 1). First, several mobility-related activities were performed in a fixed order: walking 4.5m, sitting in the chair, walking 2.3m, stair walking, walking 1.4m, lying supine and side-lying (right/left) in the bed, walking 1.4m, stair walking, walking 2.3m, picking up a tray with 2 cups from a table, and walking 4.5m. The subjects had to stand still for approximately 3 seconds after each activity. A test instructor walked alongside the subject and indicated when to start the next activity. This fixed sequence was performed 5 times consecutively. If necessary, subjects were allowed to take a break after completion of a sequence until they were ready to continue. Thereafter, the subjects could move freely for 3 minutes with the only instruction that taking the stairs, sitting in the chair, and lying in bed had to be completed at least once. All measurements were recorded on

video. The video camera was positioned perpendicular to the set-up, so the activities were mainly assessed from a side view.

For study 2, subjects were monitored for about 30 minutes in their home environment while performing similar activity sequences as in study 1: sitting in a chair, lying in bed, walking (15m outside), stair walking (if present), taking a tray from one table to another table, and walking for several periods in between. Also, the subjects were asked to carry out common tasks in and around the house such as doing the dishes or watering plants. A test instructor gave directions and recorded the subjects' movements with a handheld video camera.

Data Analysis

The video recordings were digitized and scored in a video analysis program designed in MATLAB 7.1.[b] After scoring the data of 2 to 3 subjects for training, a research assistant with a master's of science in human movement sciences and a master's student in human movement sciences independently observed 10 subjects to determine the interrater reliability of activity durations based on observations of the start and end of walking (including stair walking), sitting, standing, and lying. Intraclass correlation coefficients (2-way random, absolute agreement) values were, respectively, .94, .60, .97, and .99. The remaining videos were scored by the research assistant, whose ratings were used for evaluation.

Walking was determined, starting from the heel-off for the initial step until ending with full floor contact of the foot making the last step, and the number of steps taken 2 or more. A step was defined as a forward displacement of the foot together with a forward displacement of the trunk. Persons were considered to be sitting when their upper body was upright and at a 90° angle to the legs. Standing was determined when the subject was in an upright position with no or a small displacement, but no distinctive steps, of the feet. Lying was defined as the person being in a horizontal position and either the side or the back of the body contacting the bed completely. All activities were coded by a number representing one of the activity categories. Postural transitions (standing to sitting or lying and vice versa) were not scored but left open as blank periods.

The video recordings in the home environment were observed by a human movement sciences student. Because more situations were expected in which subjects would not actually walk, but also would not completely stand still, the category shuffling was included and defined as locomotion by means of 1 step or several incomplete steps.

The MiniMod data were uploaded on an internet site (http://www.gaitweb.nl) of the supplier for blind analysis. The DynaPort MoveMonitor gait and posture detection algorithm consists of 5 major parts. The first step is gait period detection based on an intensity threshold. These potential gait periods are scanned using frequency analysis and a validated step detection method,[30-33] resulting in 3 categories: walking, active (but not walking), and static periods. Second, transition detection is performed to identify upward or downward transitions. The result is the identification of either up (standing) or down (lying or sitting). Subsequently, angle calculation based on sensor tilt is used to determine whether the down part of this vector can be identified as lying ($<30°$) or sitting. Next, shuffling separation divides the active (not walking) parts into 2 categories: shuffling and transitions. Shuffling is defined as all movement from A to B that is not walking. Thus, if the number of steps is less than 3 or the intensity and direction of the motion do not comply with the characteristics of walking, the movements are classified as shuffling. Finally, larger transitions (eg, standing to lying) are split in 2 and merged with the activity before and after the transition. The results of the software analysis were returned by e-mail in Excel files.[c] The reports listed the start and end times of each activity together with the associated classification category.

The performance of the activities as observed on video was taken as the criterion measure. The video scores and the results of the MoveMonitor were compared in a program also written in MATLAB. After synchronization of the video and the MoveMonitor data, the correspondence between the activity codes was determined with a time resolution of 0.1 second. First, the total correspondence or noncorrespondence between the 2 methods was calculated for all the subjects together by adding up per activity the duration that the activity codes matched or differed and expressing it as a percentage of the total duration that an activity was observed on video. Subsequently, sensitivity, specificity, and predictive values were calculated per subject for each activity category. For example, the values were calculated for sitting as follows:

1. Sensitivity = (total duration that the video observation and the MoveMonitor corresponded at the same moment for sitting/total duration that sitting was observed on video) · 100%
2. Specificity = (total duration that the video observation and the MoveMonitor corresponded at the same moment for not sitting/total duration that not sitting was observed on video) · 100%
3. Positive predictive value = (total duration that the video observation and the MoveMonitor corresponded at the same moment for sitting/total duration that sitting was reported by the MoveMonitor analysis) · 100%

Also, overall agreement scores were calculated per subject by taking the activity categories together, as follows:

4. Overall agreement = (total duration that the video observation and the MoveMonitor corresponded at the same moment for all categories/total duration that the activities were observed on video) · 100%

Statistical analyses and calculations were performed in SPSS 15.0[d] and Microsoft Office Excel 2007. Effects of disease stage on sensitivity and overall agreement have been tested by 1-way analysis of variance at a significance level of P less than .05.

RESULTS

In study 1, one patient with PD was not able to complete the protocol because of fatigue. Another patient with PD had many freezing periods, which complicated distinguishing standing from walking in the video observation. Also, in 2 cases, the Secure Digital card was accidentally switched to the locked position when it was put in the MiniMod, so no data were recorded. Therefore, the data of 28 subjects have been used for analysis. According to the Hoehn and Yahr scale, these patients were in stage I (n=11), II (n=9), or III (n=8) of the disease. Except for the subject with freezing of gait, none of the other patients with PD in study 1 and study 2 reported serious fluctuations in performance because of on-off effects of the anti-Parkinson's medication.

Mean activity durations as observed on video (table 1) were shorter in the laboratory (fixed and free) than in the home environment. Table 2 presents the percentages of total correspondence and noncorrespondence between the output of the DynaPort MoveMonitor and the video observation. Mean sensitivity, specificity, and positive predictive values are given in table 3. In study 1, overall agreement per subject ranged between 69.8% and 90.8% (mean ± SD, 81.4±5.5%) for the fixed sequence and 57.5% to 96.9% (mean ± SD, 87.2±9.5%) for the free sequence. No statistically significant differences were found between Hoehn and Yahr groups for both tasks in

Table 1: Activity Characteristics Based on the Video Observation

	No.			Mean Duration ± SD			Total Duration		
	Laboratory			Laboratory			Laboratory		
Category	Fixed	Free	Home	Fixed	Free	Home	Fixed	Free	Home
Lying	139	51	17	15.7±6.0	12.9±7.9	33.4±15.3	36.4	11.0	9.4
Sitting	208	95	63	2.5±1.4	3.4±5.0	38.3±51.3	8.8	5.4	40.7
Standing	1204	139	239	2.5±2.1	2.8±1.7	16.4±35.5	51.0	6.4	65.3
Walking	1112	492	267	4.1±1.7	5.9±5.7	8.9±6.3	76.8	48.2	39.5
Shuffling	ND	ND	101	ND	ND	3.4±2.7	ND	ND	5.8
All	2663	777	687	3.9±3.7	5.5±5.8	14.0±28.1	173.0	71.0	160.7

NOTE. Mean duration is expressed in seconds and total duration in minutes. Sitting also included sitting on the edge of the bed as part of getting out of the bed.
Abbreviation: ND, no data.

the laboratory. In study 2, overall agreement per subject ranged between 60.0% and 89.2% (mean ± SD, 77.8±12.1%).

DISCUSSION

The aim of this study was to determine the accuracy of a single device accelerometry-based method to detect gait and postures in patients with mild to moderate PD. The DynaPort system was tested while patients performed common mobility-related activity sequences in a standardized setting and in a home environment.

Disease severity, as measured by Hoehn and Yahr stage, did not influence detection accuracy. Lying was detected almost perfectly in all circumstances. Overall, detection of walking was satisfactory, although very short walks like the 1.4-m trajectories in the laboratory were frequently classified as shuffling. Furthermore, when subjects stepped slowly or paused for a moment on the 3-step stair, walking was often classified as shuffling. Of course, it remains disputable whether such activities should be considered walking. However, at home, shuffling was not accurately detected and also proved complicated to evaluate by video observation. For example, when working in the kitchen, a subject alternated several times standing briefly with making a few steps. In this and similar situations, it was not easy to discriminate shuffling from standing and walking.

Moderate results (sensitivity=60.9%–85.4%) have been found for the detection of sitting and standing, particularly in the laboratory, where the mean duration of these events was 2.5 to 4 seconds. Such brief activities were difficult to detect. Especially a lot of the sitting periods on the edge of the bed remained undetected. This also explains the misclassification of sitting as standing or lying, which was the preceding or following activity. Apart from this, lower interobserver agreement for sitting existed, mainly a result of differences in the number of sitting periods on the edge of the bed. So, both missing of short event durations and observation disagreements may have influenced the correspondence values for sitting. In this study, missing short sitting periods—for example, as part of getting out of bed—had large consequences. However, on measurements for days or weeks, it will have only limited effect. The mean sensitivity for sitting was best in the home environment, where the mean duration was up to 10 times longer. Short standing periods were detected well, but frequent small differences with the video observation led to a lower correspondence. At home, the MoveMonitor reported in some occasions sitting when a subject was standing and bending forward while doing the dishes or getting books from a low cupboard. This might be problematic because patients with PD can have a more stooped posture. Conversely, a few evident sitting periods in a chair were misclassified as standing.

By the same experimental procedures, the DynaPort system has also been tested in community-dwelling older adults.[28] Corresponding to the present study, detection of walking and lying was good to excellent, whereas sitting and standing were predominantly less well detected with the lowest outcomes obtained in the laboratory. Mean overall agreements were equal or only slightly (1.5%–2%) better than those in the patients with PD, suggesting that the DynaPort method was not significantly affected by typical parkinsonian movement problems. In other studies validating single-device systems in healthy (older) adults and patients with COPD, higher sensitivity for sitting, standing, and walking was reached, ranging from 89.9% to 100%.[25-27,29] Yet to our knowledge, these validations did not include activities shorter than 5 seconds,

Table 2: Total Correspondence and Noncorrespondence Between the Video Observation (Rows) and DynaPort (Columns) per Activity Category

DynaPort	Lying			Sitting			Standing			Locomotion			Shuffling		
	Laboratory			Laboratory			Laboratory			Laboratory			Laboratory		
Video	Fixed	Free	Home	Fixed	Free	Home	Fixed	Free	Home	Fixed	Free	Home	Fixed	Free	Home
Lying	99.9*	99.8*	98.9*	0.1	0.2	0.2	0	0	0.5	0	0	0.4	0	0	0
Sitting	9.8	1.1	2.7	64.7*	68.9*	83.2*	20.8	21.8	12.7	0.7	6.6	1.3	4.0	1.6	0.1
Standing	0.3	0	0.8	0.6	0	18.3	69.6*	65.7*	73.3*	20.3	31.5	7.1	9.2	2.8	0.5
Walking	0.1	0.4	0.3	0	0.1	1.5	5.6	5.6	8.1	82.1*	89.3*	83.3*	12.2	4.6	6.8
Shuffling	ND	ND	1.4	ND	ND	12.9	ND	ND	40.8	ND	ND	37.2	ND	ND	7.7

NOTE. Values are expressed in percentages.
Abbreviation: ND, no data.
*Total correspondence.

Table 3: Mean Sensitivity, Specificity, and Positive Predictive Values (%)

	Sensitivity			Specificity			Predictive Value		
	Laboratory			Laboratory			Laboratory		
Category	Fixed	Free	Home	Fixed	Free	Home	Fixed	Free	Home
Lying	99.9	99.7	99.3	76.5	85.2	76.4	96.5	97.7	84.4
Sitting	64.6	60.9	85.4	82.4	88.7	75.7	95.0	95.9	76.8
Standing	68.4	63.5	74.4	86.8	89.3	80.5	86.2	53.6	81.4
Walking	83.8	89.5	81.7	79.8	82.2	76.4	85.7	94.7	82.8
Shuffling	ND	ND	6.4	ND	ND	80.4	ND	ND	31.4

Abbreviation: ND, no data.

and neither did these studies use a time resolution of 0.1 second. Our study on gait and posture detection was based on a precise analysis of a large number of fairly short activities. As such, this evaluation was quite challenging and unforgiving, certainly during the laboratory tasks. Detection was generally better in the home environment, where participants could perform subsequent activities at a slower pace. Results may further improve during prolonged monitoring, when patients with PD are expected to have longer periods of inactivity. Measurements without continuous supervision may require consideration, because on a few occasions, displacements of the belt needed realignment by the test instructor. In participants with a cone-shaped trunk, the belt moved in the caudal-cranial direction, which might affect the detection of sitting and lying. When participants had difficulty turning over in bed, displacements of the belt in the medial-lateral direction could have influenced the detection of postural transitions. Establishing the correct position of the MiniMod may be difficult for the subjects themselves; however, putting a piece of colored tape at the front and in the middle of the belt as an indicator can be helpful. To prevent relative movements of the device on the trunk, it is important that the belt is strapped tightly. Because of its elasticity, this has almost no effect on comfort and awareness of the device.

CONCLUSIONS

The DynaPort MoveMonitor is a practical and valuable tool for objective, continuous assessment of walking and postures in patients with mild to moderate PD (stages I–III). In the present study, the time spent walking and lying was accurately detected. Detection of sitting and standing requires further fine-tuning. Additionally, validity in patients with severe PD (stage IV) or complications like freezing and on-off symptoms has to be examined. Because specific evaluation procedures, such as the inclusion or exclusion of brief activities, may influence outcomes, it is suggested that some standardization must be achieved to compare future validations of activity monitoring methods better.

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Suppliers

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