Activity monitor placed at the non-paretic ankle is accurate in measuring step counts during community walking in post-stroke individuals: a validation study

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Abstract

Background. Different environmental factors may affect the accuracy of step-count activity monitors (AM). However, the validation conditions for AM accuracy largely differ from ecological environments.

Objectives. To assess and compare the accuracy of AM in counting steps among post-stroke individuals: during different locomotor tasks, with AM placed at the non-paretic ankle or hip, and when walking in a laboratory or inside a mall.

Design. Validation study.

Settings. Laboratory and community settings.

Participants. Twenty persons with chronic hemiparesis, independent walkers.

Methods. 1st session: participants performed level walking (6MWT), ramps and stairs in the laboratory with AM placed at the non-paretic ankle and hip. 2nd session: participants walked a mall circuit, including the three tasks, with AM placed at the non-paretic ankle. The sessions were video-recorded.

Main Outcome Measurements. Absolute difference between the steps counted by AM and the steps viewed on the video-recordings (errors, %); occurrence of errors >10%.

Results. Median errors were similar for the 6MWT (0.86 *(0.22, 7.70)*%), ramps (2.17 *(0.89, 9.61)*%) and stairs (8.33 *(2.65, 19.22)*%) with AM at the ankle. Step-count error was lower when AM was placed at the ankle (8.33 *(2.65, 19.22)*%) than at the hip (9.26 *(3.25, 42.63)*%, p =.03). The greatest errors were observed among the slowest participants (≤0.4 m/s) on ramps and stairs, while some faster participants (>1 m/s) experienced the greatest error during the 6MWT. Median error was slightly increased in the mall circuit (2.67 *(0.61, 12.54)*%) compared to the 6MWT (0.50 *(0.24, 6.79)*%, p = .04), with more participants showing errors >10% during the circuit (7 vs. 2, p = .05).

Conclusions. Step counts are accurately measured with AM placed at the non-paretic ankle in laboratory and community settings. Accuracy can be altered by stairs and ramps among the slowest walkers and by prolonged walking tasks among faster walkers.

Level of evidence: IV

Introduction

After a stroke, a low level of physical activity contributes to several secondary physical and psychological disorders, including poor health-related quality of life [1]. Being involved with personally meaningful activities, such as community-based activities [2], is essential for life satisfaction [3]. A person capacity to go into the community is commonly predicted by walking speed [2,4]. After a stroke however, there is often a discrepancy between what a person can do (motor capacity, such as clinical walking speed tests) and what a person actually does (motor performance) during the day [5,6]. The number of steps individuals take during the day is a good indicator of community-based activities and walking performance [7,8], and thus informs clinicians about the related physical and psychological components of health [1,9]. Healthcare professionals and researchers need precise devices, evaluated by well-defined protocols, to assess and inquire on walking performance in the community. Ideally, the devices should be precise regardless of the individuals' sensorimotor and functional levels of deficit, which are heterogeneous among post-stroke individuals [10].

Previous studies have revealed that consumer-based activity trackers are inaccurate in monitoring walking activity in slow walkers (<0.8 m/s) [11,12]. In this context, one activity monitor has received particular attention. When the evaluated device is placed at the hip (as recommended by the manufacturer) in older healthy subjects walking slower than 0.8 m/s, its step error rate is higher than 10% [13] (i.e. arbitrary threshold used previously and considered acceptable [14]). The inaccuracy of the monitor when placed at the hip while walking slowly is a significant limitation considering that many individuals with disabilities, including those with post-stroke hemiparesis, have a self-selected gait speed under 0.8 m/s [15]. The error rate of the evaluated monitor tested with short distances (15 m) and in a straight-ahead direction became acceptable (<10%) for speeds as slow as 0.4 m/s when the device was placed at the right ankle in older healthy adults [13] or at the non-paretic ankle in post-stroke individuals [16]. This observation was recently replicated in a clinical context. During post-stroke rehabilitation physical therapy sessions, with at least 30 minutes of gait retraining, the mean difference (standard deviation *(SD)*) between the actual number of steps and the count provided by the monitor was 10.9 *(5.3)*% for the slowest participants (walking speed <0.4 m/s, n = 12 participants) and 6.8 *(3.0)*% for participants with a walking speed between 0.4 and 0.8 m/s (n = 7) [17]. Placing the evaluated monitor at the non-paretic ankle was thus considered as appropriate for monitoring walking activities in post-stroke individuals in a rehabilitation setting.

It must be noted that the validation conditions proposed in the literature largely differ from daily ambulatory activities in the community. Ambulatory factors that individuals encounter when out in the community such as ramps and stairs [18] are known to affect the accuracy of consumer-based monitors [19,20]. Most activity monitors fail to count steps properly on stairs, ranging in error from 10% to 41% in healthy adults [14]. A more distal placement of the monitor, rather than it being on the hip, has also been suggested to improve step-count accuracy on stairs [20], but this has yet to be tested. Another issue is that most studies report having tested monitors accuracy over a short distance (15 m) with the monitor placed at the ankle while walking on level ground. Only one study investigated the validity of monitors in measuring step counts during the 6-minute walk test (6MWT), among inpatients including some post-stroke individuals [21]. This may indeed represent the minimal distance required for outings in the community after discharge [6,22]. However, an even better strategy would be to test the accuracy of the monitor in real-life situations where different aspects of locomotion are encountered such as walking with abrupt changes in speed and direction (to avoid other pedestrians, for example), as well as ramps and stairs. These factors might affect the activity monitor accuracy compared to walking straight ahead over a long distance such as during the 6MWT [23]. Thus, the accuracy of the monitor should be tested in a real-life setting to adequately portray what post-stroke individuals have to deal with as they go about their daily activities.

The aim of this study was thus to assess and compare the accuracy of an activity monitor in counting steps among post-stroke individuals. The effects of locomotor tasks (walking for a long period of time (6MWT), going up and down a ramp and going up and down stairs) and placement of the monitor (at the non-paretic ankle or hip) were tested, in the first part of the study. The effect of the setting (a laboratory or a shopping mall) was tested, in the second part of the study. The hypotheses were that the accuracy of the monitor placed at the ankle would be 1) similar between tasks, 2) better compared to the hip placement. In addition, step count would be less accurate in the ecological situation compared to the controlled clinical situation. The relationship between ecological and clinical accuracy was tested as well.

Method

Participants and settings

This cross-sectional study was conducted from August 2016 to August 2017. Recruitment of a convenience sample of participants (n = 20) was conducted via: 1) the consultation of a list of hemiparetic persons who previously participated to other projects and agreed to be contacted again, 2) the diffusion of the presentation pamphlet of the study among a local exercise group for people with hemiparesis. Eligibility criteria were: at least 6 months post stroke, ability to walk independently and safely in the community (with or without a walking aid), and presence of residual sensorimotor deficits at the paretic lower limb. Individuals with additional disorders (orthopedic, musculoskeletal, etc.) that could affect their locomotor abilities were excluded. Participation included two sessions (separate from 7 to 10 days), at two different locations. The first session took place inside our gait analysis laboratory. The second session took place inside a shopping center *(#1 - affiliation suppressed – blinded peer-review)*. Residual lower-limb motor function was assessed with the Chedoke-McMaster Stroke Assessment during the first session (**Table 1**). Ethics approval was obtained from the Ethics Committee of the *(#2 - affiliation suppressed – blinded peer-review)*, and written informed consent was obtained from all participants.

Device

The monitor used in this study (Fitbit® One) is a small (4.8 × 1.9 × 1.0 cm), commercially available device containing a tri-axial accelerometer that converts inertial characteristics of movement into step counts based on proprietary algorithms. This low-cost piece of equipment is easy to use and provides immediate feedback about the number of steps.

Procedure

For the laboratory session, two monitors were attached by a clip (on the back of the device) to the participant's sock (ankle placement) and to the front pocket (or waist) of the participant's pants (hip placement) on the non-paretic side. Participants were asked (randomly) to go up and down an access ramp (four times) and up and down a set of four steps (four times) in our laboratory. Each participant also completed the 6MWT (back and forth over a 30-m path) in a quiet corridor.

For the session at the shopping center, the monitor was attached by its clip to the participant's sock on the non-paretic side. A circuit inside the shopping mall was chosen. It involved going up and down an access ramp (twice), going up and down eight steps (twice), walking on level ground on two different floors (transition by elevator) to reach a grocery store, and then going back through the circuit encountering all the same obstacles (**Appendix 1**). The total distance of the circuit was 615 m. Participants were asked to walk at their self-selected walking speed, "as if they were alone and out shopping." They were told that they could rest as often and as long as necessary.

Data collection

Step counts displayed on the monitors were observed and recorded before and after the 6MWT, ramp and stair tasks in the laboratory and before and after the circuit inside the mall. The tasks were video-recorded (Samsung, HMX-QF20) by a research assistant who followed the participant with a camera.

Data analysis

For each task, the step count was the difference in the number of steps displayed on the monitor between the beginning and end of the task ($\text{Steps}_{\text{Fitbit}}$). The number of steps counted on the video-recordings ($\text{Steps}_{\text{Video}}$) was used as a reference. A step was counted when the heel or toes (having left the ground) struck the ground again [14]. Two independent reviewers counted the steps taken by the non-paretic leg (i.e. the one wearing the monitor) based on the video-recordings for the circuit and 6MWT tasks. For each participant, if the difference between the two reviewers' counts was greater than one step for the mall circuit or the 6MWT, a consensus was reached following a second viewing of the video recording and a discussion with a third viewer. When no further discussion was needed, one of the reviewers then counted the steps from the videos for the ramp and stair tasks. To obtain the total number of steps, the number counted on the video (i.e. non-paretic steps) was doubled and then compared with the step count recorded on the monitors.

Walking speed was also calculated during level walking. The 6MWT walking speed was obtained by dividing the distance covered during the test by 360 seconds. In addition, the circuit walking speed was measured based on the video-recordings by using the average time it took participants to walk along two, marked 10-m sections during the first part of the circuit.

Gait pattern was assessed subjectively by a physical therapist researcher (N.C.D.) with 8-years experience. She viewed the video recordings of the participants walking along the two, marked 10-m sections of the circuit, categorized their gait as “normal” or “abnormal” [24] and described the main disturbances [25] (**Table 1**). In addition, the walking aid and strategy used by the participants to go up and down the stairs (step-over-step (SOS) or step-by-step (SBS)) was noted (**Table 1**).

Statistical analysis

The accuracy of the monitor was assessed for each task using an error value calculated as: (absolute value $|\text{Steps}_{\text{Fitbit}} - \text{Steps}_{\text{Video}}|$) / $\text{Steps}_{\text{Video}} \times 100$. A positive value for the difference between $\text{Steps}_{\text{Fitbit}}$ and $\text{Steps}_{\text{Video}}$ indicated over-counting, with extra steps being detected by the Fitbit® One monitor. A negative value indicated under-counting by the monitor (missed steps). Both over- and under-counting were errors. We thus chose to consider absolute difference values in order to calculate the error rate (%) in the analysis. An error rate lower than 10% was interpreted as acceptable [14,16]. Normality of the distribution of errors was checked for all tasks with a Shapiro-Wilk test, revealing that non-parametric statistics were indeed required.

Descriptive statistics were used for each task (i.e. median, first quartile (Q1) and third quartile (Q3)). The interquartile range (IQR) was defined by Q3 - Q1. Any error that fell more than 1.5 times the IQR below Q1 or above Q3 was considered as an outlier value. For boxplot representations, the adjacent values were defined as the highest value above Q3 which was not an outlier, and the smallest value below Q1 which was not an outlier.

In the first part of the study, a Friedman ANOVA was used to assess whether the errors varied with the ambulatory tasks. Spearman rank-order correlation coefficients were used to estimate whether errors during the 6MWT, ramp and stair tasks were correlated. A Wilcoxon signed-rank test was used to compare errors between ankle monitor placement and hip monitor placement, during the 6MWT, ramp and stair tasks. For the Wilcoxon test, participants were excluded of the analysis in case of missing data in at least one condition. To determine the influence of gait pattern and stair strategy on the error, we also assessed whether gait pattern influenced accuracy of the device using a visual analysis.

In the second part of the study, a Wilcoxon signed-rank test allowed for the comparison of errors during the circuit at the mall and the 6MWT. A Spearman rank-order correlation coefficient was calculated to estimate their relationships. In addition, the number of “unacceptable” errors (>10%, [14]) in the group was compared between the 6MWT and the circuit with a Chi-squared test. Statistical analyses were performed using IBM SPSS Statistics 24.0 software. Significance was set at an alpha level of < .05.

Details relating to number of steps in each task (**Table SI**) as well as Bland-Altman plots (**Figure SI**) are presented in supplementary data.

Results

Twenty participants were recruited. For data collection of the first seven participants, the monitor placed at the hip was not used. In addition, technical difficulties with the monitor lead to inappropriate data collection in three participants: their data in the ramp and stairs tasks were excluded from the analysis. Among the next thirteen participants, one did not participate in the second session due to his lost of interest in the study (**Table 1**).

With the evaluated monitor placed at the hip (n = 13), the errors (i.e. absolute difference between the steps counted by the monitor and the steps viewed on the video-recordings, %) were lower during the 6MWT than during the ramp and stair tasks ($\chi^2(2) = 7.54$, $p = .02$; post-hoc analysis: $z = -2.48$ and -2.55, $p = .008$; **Figure 1**). The errors were significantly correlated between the 6MWT and ramp task ($r_s = .61$, $p = .02$) and the ramp task and stair task ($r_s = .61$, $p = .03$). With the monitor placed at the ankle (n = 17), the errors were similar during the 6MWT, ramp and stair tasks ($\chi^2(2) = 5.76$, $p = .06$; **Figure 1**). The errors observed during the different tasks (6MWT, ramp and stairs) were not significantly correlated (p > .33).

Step count errors were significantly decreased with the monitor placed at the ankle (median *(Q1, Q3)*: 8.33 *(2.65, 19.22)* %) compared to it being placed at the hip (9.26 *(3.25, 42.63)* %) when going up and down stairs ($z = -2.13$, $p = .03$; **Figure 1**). Of the 93 *(20)* steps (mean *(SD)*) taken by the participants to go up and down the stairs, 78 *(28)* steps were counted by the monitor placed at the ankle whereas only 61 *(30)* were counted by the monitor placed at the hip (**Table S1**). During the 6MWT and ramp tasks, the placement of the monitor did not significantly affect the error (z = -0.31, p = .75 and z = -1.57, p = .12, respectively).

Individual data (**Figure 2**) for ankle and hip placements revealed that for the two slowest participants (1. and 2., walking speed ≤0.4 m/s; each walked with a specific gait pattern: circumduction vs. shuffling; both climbed stairs using a SBS strategy), the monitor underestimated the step count by more than 50% during the ramp and stair tasks. One participant (5.) climbed stairs using a SBS strategy and had an acceptable error (3.0%) when the monitor was placed at the ankle. All participants walking slower than 0.8 m/s had an acceptable error during the 6MWT with the monitor placed at the ankle whereas some participants with faster walking speeds (>0.8 m/s; 15. and 16.) also experienced an unacceptable error. All participants who walked faster than 0.8 m/s had an acceptable error during the 6MWT with the monitor at the hip.

The errors that occurred during the circuit inside the mall (2.67 *(0.61, 12.54)* %, n = 19) were significantly superior to the errors that occurred during the 6MWT (0.50 *(0.24, 6.79)* %, z = -2.61, p = .04; **Figure 3-A**). The participants took an average of 1532 *(423)* steps during the circuit which were counted as 1441 *(373)* steps by the monitor. For the 6MWT, the number of steps was 617 *(152)* whereas 588 *(144)* steps were counted by the monitor (**Table 2**). The correlation between the errors obtained during the circuit and the 6MWT was significant (r_s = 0.77, p < .01), but a >10% error rate occurred more frequently during the mall circuit (7/19 participants: 1., 3., 14., 13., 8., 15. and 17., 37% of the sample) than during the 6MWT (2/19 participants: 15. and 17., 10.5% of the sample; χ^2 = 3.83, p = .05; **Figure 3-B-C**). When the error was unacceptable during the 6MWT, it was also unacceptable during the circuit (**Table 3**). Except for one participant during the circuit (11., overestimated step count; **Table 2**), errors greater than 10% were always an underestimation of the steps counted by the monitor. These errors were observed for the slowest participants (circuit) and for some of the fastest participants (6MWT and circuit). We did not find any specific gait abnormalities associated with these findings.

Discussion

The main results of this study are: 1) When counting steps on stairs, the evaluated monitor was more accurate when it was placed at the ankle than when it was placed at the hip, on the non-paretic side. However, step counts during other locomotor tasks overall were not influenced by the position of the monitor; 2) For very slow walkers (≤0.4 m/s), the monitor placed at the non-paretic ankle accurately measured the number of steps during level walking, but not during other locomotor tasks; 3) For faster walking participants (>0.8 m/s), step count errors were always considered as acceptable with the device positioned at the hip during level walking, but not when it was placed at the ankle. 4) Step-count errors observed during the 6MWT and throughout the circuit in the community were significantly correlated but were considered unacceptable (>10%) more frequently during the circuit.

Our group of participants adequately represented the heterogeneity of walking capacity among post-stroke individuals. Their walking speeds in the community ranged from 0.3 m/s to 1.2 m/s, and up to 1.7 m/s during the 6MWT. They generally used various walking aids and had different gait abnormalities when walking on level ground (shuffling, stiff knee, hip hike, etc.) and on stairs (step-over-step, step-by-step or a mix of both). It was relevant to include several walking capacities to support the generalizability of our results since slow walking speeds (<0.8 m/s), walking aids and post-stroke gait abnormalities are known to affect step count accuracy by monitors and pedometers [24,26]. Activity monitors step counting requires an automatic detection of steps in accelerometric signals. It might be possible that step count would be more altered among populations walking with high gait variability, like people older than the recruited sample [27] or with subacute hemiparesis [28].

Placing the monitor at the ankle improved its accuracy in counting steps on stairs, as shown by the comparison conducted on data obtained when the monitor was located at the hip (position recommended by the manufacturer). When placed at the hip, the monitor accuracy in counting steps was inconsistent between participants, with a median error of 10% indicating that the monitor miscounted the steps in half of the subjects. As for the slowest participants, the error rate reached 100%, which means that no step was counted by the monitor when the subject went up and down stairs. This is consistent with earlier results observed in healthy subjects [14,20]. The acceleration at the hip might be too low to be detected as a step, and a more distal placement of activity trackers has been suggested to improve performance, given that higher accelerations occur at more distal segments when going up and down stairs [29]. However, in a previous study, the placement of a spring-levered pedometer at knee level in stroke and healthy adults failed to improve the consistency of step counts on stairs. In addition, there was no relationship between the number of steps on the stairs and the number of steps counted, regardless of the hip or knee position of the tracker [30]. It seems that placing the monitor at the ankle, as tested in our study, reduces the errors that occur but no one position provides an acceptable step count on stairs for participants walking under 0.4m/s. The errors were also not acceptable when participants with a speed under 0.4 m/s walked on a ramp. The ramp slope in the laboratory was set to 11% and may have therefore altered the accuracy of the step count as suggested by Leicht and Crowther[19] with inclinations ≥ 9%. The slope of the ramp may alter the accelerometric pattern of the step during slow walking and contribute to an inaccurate step count. The proprietary algorithms used by the monitor are confidential, but the failures that lead to the errors in ramp and stair tasks might be different, since errors in both tasks were not correlated when the monitor was placed at the ankle. In addition, algorithms are specific to each company and monitor, and the effect of monitor placement and locomotor tasks on step-counting accuracy of other monitors than the one evaluated in this study should be further explored within a larger sample and including a larger proportion of slow walkers.

In contrast with previous studies [13,16], placing the monitor at the ankle did not significantly decrease the step count error while walking on a level ground. However, individual data revealed that for the slowest walkers (<0.8 m/s during the 6MWT), step count errors which were >10% with the monitor at hip level, were lower than 10% with the monitor at the ankle. ~~This is an important finding that~~ This result supports placement of activity monitors at the non-paretic ankle to count steps accurately among post-stroke individuals walking slower than 0.4 m/s on level ground for longer periods of time. However, these observations were different among those who walked faster than 0.8 m/s, suggesting that monitors should be placed at the hip among these participants to ensure an accurate step count. A practical recommendation should be to assess gait speed and place the activity monitor on the hip or ankle according to the speed measured. The lack of a significant difference between errors with the monitor placed at the ankle and hip is probably affected by the small sample size and the heterogeneity of the observed errors. However, the difference between the two placements is evident in slow walkers. This suggests that slow and fast walkers should be considered in separate groups in future studies. Further analysis of acceleration time-series data might help to clarify why the ankle position of the evaluated monitor is not the best position for counting steps in faster post-stroke walkers.

Limitations

Walking in the community is a more complex task than the 6MWT. For example, it included situations where participants turned with successive movements of the non-paretic foot on the floor, slightly rotated without any sagittal acceleration or moved in the elevator with multiple small backward steps. We counted all these foot movements as a step. These situations probably contributed to the error obtained in the circuit task. Similar difficulties have already been observed during household activities when performed at slow ambulation speeds and with shuffling-like steps. In these cases, lower step count accuracy has been reported with monitors [14]. One limitation of the study is that it is not possible to infer on step counts to determine when exactly the steps were missed, since the monitor display screen was only viewed at the beginning and the end of the circuit. However, the observations made during the ramp and stair tasks in the laboratory suggest that step counts during these locomotor activities might be more problematic than during level walking. Overall, our results highlight the need for improvements in activity monitor algorithms to allow quantification of walking activity in realistic and ecological conditions regardless of walking speed and gait deviations of individuals post stroke.

The errors obtained during the community-based circuit give a realistic indication as to the quantity of steps that might be miscounted by the monitor during a period of monitoring. However, another limitation of this study is that the characteristics of the circuit chosen in the community might have increased the error reported for slow walkers. Indeed, the circuit required participants to go up and down the ramp and stairs four times each, and steps were likely not accurately counted by the monitor, as shown in the first part of the study. In a real-life situation, a person with mobility disabilities would likely have used stairs only once while at a shopping center [31]. Therefore, a fewer number of steps would be missed compared to the proposed circuit. In addition, considering the barrier that stairs represent for physical activity after stroke [18], slow walkers are less likely to climb stairs frequently than the faster walkers. The inability of the monitor to accurately count steps on stairs in very slow walkers might have a minor impact on the value obtained after a monitoring period where stairs and ramps are encountered less frequently. A recent study recommended assessing agreement between the step counts recorded by an activity monitor and the steps counted by a therapist before any activity monitoring [21]. Our results suggest that a 6MWT could be an appropriate test and further studies are needed to confirm if the error observed during the 6MWT is predictive of the actual error in a real-life setting.

Conclusions

Placing the monitor at the ankle seems to be the more appropriate position for counting steps during the three tested ambulatory activities (walking for a long period, going up and down a ramp and going up and down a set of stairs). In most of the participants, the inaccuracy of the step count observed in a real-life setting is small enough to enable health professionals to appropriately infer on walking performance in the community among post-stroke individuals after discharge and long-term follow-up. However, steps can be inaccurately counted during different activities, such as stairs among slow walkers and long periods of walking among faster walkers. The impact of these inaccuracies on monitored walking activity should be considered individually with regard to daily ambulatory activities. In this perspective, proprietary algorithms should be improved for monitoring other activities other than level walking among slow individuals.

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Figure legends

Appendix 1: Description and illustration of the circuit with various locomotor activities (level walking, going up and down a ramp and up and down stairs) chosen in the shopping mall *(#3 – affiliation suppressed – blinded peer-review)*. The black arrow indicates the direction of the circuit. The circuit walking speed reported in this study was calculated by using the average time it took participants to walk through two, 10-m sections in the first part of the circuit (measured afterwards using the video-recording).

Figure 1: Error boxplots (%) (with median, first (Q1) and third (Q3) quartiles, adjacent values and outliers) for steps counted by the monitor, when placed at ankle level (white columns, n = 17) or at hip level (grey columns, n = 13) on the non-paretic side, relative to the number of steps taken by individuals post stroke, during the 6-minute walk test (6MWT), going up and down a ramp and up and down stairs. The 10% dashed line represents the threshold for an acceptable error. * indicates a significant difference between conditions. There were outlier values (i.e. more than Q3 + 1.5*inter-quartile range) among the slowest participants (≤ 0.4 m/s during the 6MWT, circle) and participants with a walking speed > 0.8 m/s during the 6MWT (square), who are each represented by a color and their labels.

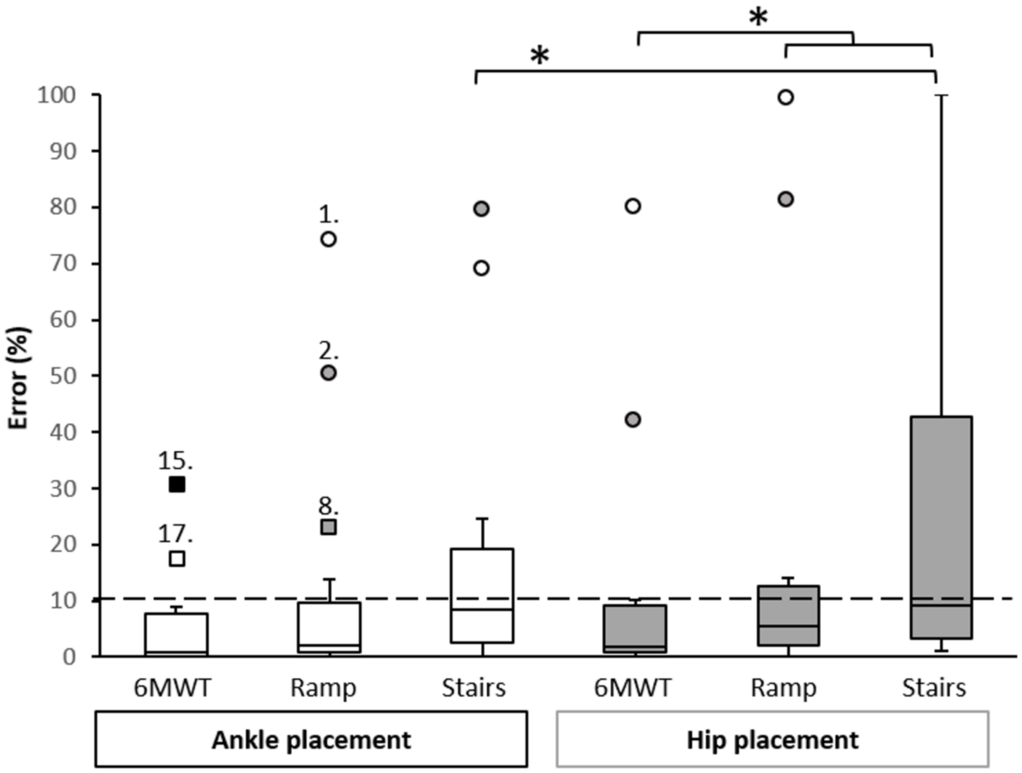

Figure 2: Error (%) made by Fitbit® One when placed at the ankle (white fill, n = 17) and at the hip (grey fill, n = 13) on the non-paretic side of each participant while walking for

6 minutes (6MWT - circles), going up and down a ramp (triangles) and going up and down stairs (squares). The walking speed during the 6MWT is indicated at the bottom, with the label of the participants.

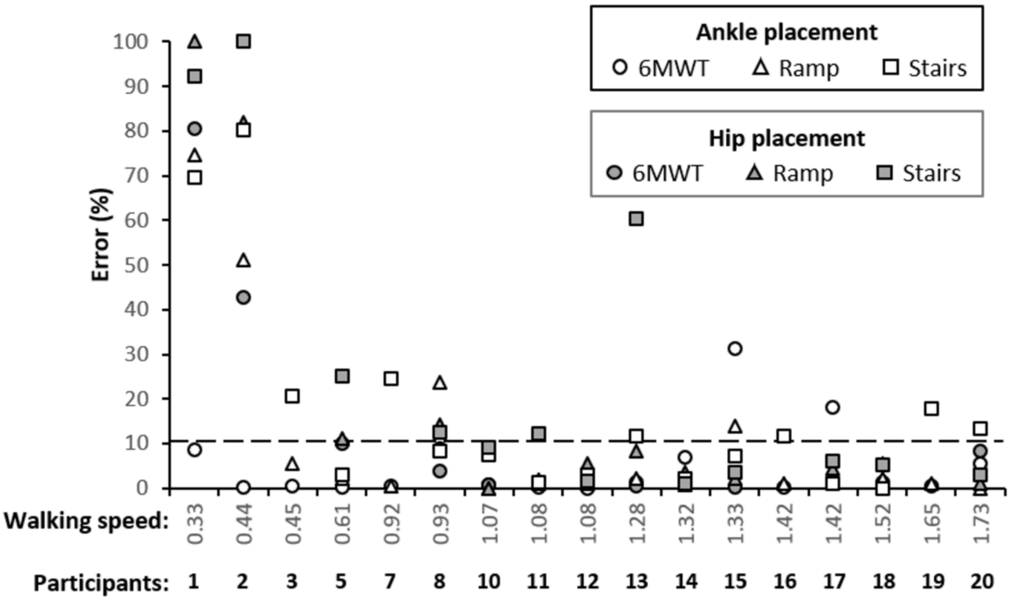

Figure 3: Error (%) for steps counted by the monitor, when placed at the ankle on the non-paretic side of individuals post stroke (n = 19) while walking for 6 minutes in a quiet corridor (6MWT, white) and through a complex circuit in the community (black): [A] For the group with boxplots (with median, first and third quartiles, adjacent values, and outliers); [B] On an individual level with respect to the walking speed during the 6MWT and [C] the circuit. The 10% dashed line represents the threshold for an acceptable error. Participant labels were added for data close to or higher than the 10% threshold.

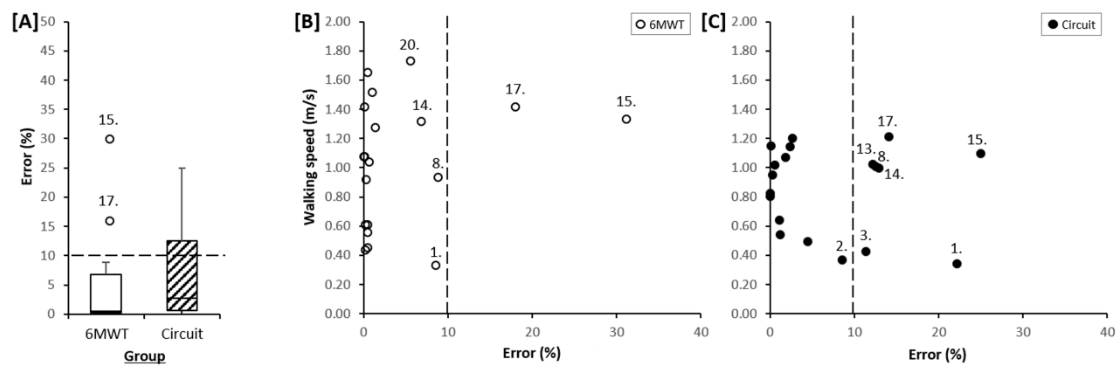
[A]
Error (%)
0
5
10
15
20
25
30
35
40
45
50
15.
17.
6MWT
Circuit
Group
[B]
Walking speed (m/s)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
20.
14.
17.
15.
8.
1.
0
10
20
30
40
Error (%)
○ 6MWT
[C]
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
17.
15.
13.
8.
14.
2.
3.
1.
0
10
20
30
40
Error (%)
● Circuit

Table 1: Individual participant characteristics and missing data (according with the monitor's placement and task performed)

	Age (years)	**Gender**	**Time post stroke** (months)	**Side of hemiparesis**	**CMSA** (Leg /7 – Foot /7)	**Distance covered in 6 minutes** (m)	**Gait abnormalities** (main disturbance)	**Walking aid**	**Stair strategy**	**Missing data** (if any)
1.	40	F	16	R	6 – 2	120	Circumduction	Quad cane	SBS	
2.	60	M	65	L	6 - 4	157	Shuffling	Stick	SBS	
3.	57	M	76	R	3 - 2	162	Knee hyperextension	Stick	SBS	Hip
4.	54	M	38	L	4 - 3	201	Circumduction	Quad cane	SBS	Hip + Ramp/stairs
5.	52	F	55	L	3 - 1	219	Stiff knee	Stick	SBS	
6.	71	F	169	L	6 - 6	219	Shuffling	Stick	SOS and SBS	Hip + Ramp/stairs
7.	47	M	65	R	6 - 7	330	Circumduction	English cane	SOS and SBS	Hip
8.	60	F	389	R	5 - 3	336	External rotation	None	SOS	
9.	62	M	58	R	5 - 1	374	None	None	SOS and SBS	Hip + Ramp/stairs
10.	57	M	17	R	6 - 2	387	None	None	SOS	Mall's circuit
11.	60	M	89	L	6 - 6	387	Circumduction	None	SOS	
12.	68	M	9	L	6 - 5	387	None	None	SOS	
13.	66	F	79	L	6 - 6	459	None	Stick	SOS	
14.	56	M	78	L	6 - 6	474	Asymmetries	None	SOS	
15.	29	F	60	L	4 - 2	480	None	Stick	SOS	
16.	42	M	67	R	6 - 6	510	External rotation	Stick	SOS	Hip
17.	41	F	231	L	4 - 3	510	Hip hiking	None	SOS	
18.	58	M	65	L	7 - 5	546	None	Stick	SOS	
19.	60	M	122	L	7 - 6	594	External rotation	Stick	SOS	Hip
20.	37	M	X	L	6 - 3	622	None	None	SOS	
Group	**53.9** *(10.8)*	**7F / 13M**	**92.0** *(86.6)*	**7R / 13L**	**5.3** *(1.2)* **– 3.9** *(1.9)*	**373.7** *(148.9)*	**7 normal / 13 abnormal**	**12 with / 8 without**	**12 SOS / 8 other strategy**	

CMSA: Chedoke McMaster Stroke Assessment; F: Females, M: Males; "X" indicates non-appropriate data (stroke at birth); R: right, L: left; SOS: step-over-step, SBS: step-by-step.

Table 2: Description of walking performance among participants (n = 19) during the 6MWT and through a complex circuit in the community, including the number of steps taken by participants ($\text{Steps}_{\text{Video}}$), steps counted by the Fitbit® One monitor ($\text{Steps}_{\text{Fitbit}}$) placed at the ankle on the non-paretic side, the monitor's rate of error (%) and the walking speed of participants. Walking speed was calculated during the 6MWT and on two, level-ground 10-m sections at the beginning of the circuit. Mean *(SD)* and median *[Q1, Q3]* values are reported for the entire group.

	StepsVideo		**StepsFitbit**		**Error** (%)		**Walking speed** (m/s)	
	6MWT	**Circuit**	**6MWT**	**Circuit**	**6MWT**	**Circuit**	**6MWT**	**Circuit**
1.	314	1920	287	1495	8.60 (-)	22.14 (-)	0.33	0.34
2.	410	2262	409	2068	0.24 (-)	8.58 (-)	0.44	0.37
3.	402	2516	400	2229	0.50 (-)	11.41 (-)	0.45	0.42
4.	430	1866	432	1782	0.47 (+)	4.50 (-)	0.56	0.49
5.	516	1994	515	1969	0.19 (-)	1.25 (-)	0.61	0.54
6.*	440	624*	442	631*	0.45 (-)	1.12 (-)	0.61	0.64
8.	640	1308	641	1304	0.67 (+)	0.00 (-)	0.92	0.95
9.	798	1308	794	1332	0.34 (-)	0.00 (-)	0.93	1.07
10.	596	1640	594	1640	0.16 (+)	0.31 (-)	1.04	0.82
11.	600	1414	604	1414	6.79 (-)	12.90 (+)	1.08	0.80
12.	780	1488	727	1296	1.40 (+)	12.54 (-)	1.08	1.00
13.	642	1734	585	1522	0.00 (-)	0.61 (-)	1.08	1.02
14.	690	1308	690	1300	8.88 (-)	12.23 (-)	1.28	1.02
15.	712	1268	722	1427	0.50 (-)	1.83 (-)	1.32	1.01
16.	860	1326	812	1294	**31.17 (-)	24.96 (-)	1.33	1.14
17.	770	1386	762	1423	5.58 (-)	2.41 (-)	1.42	1.20
18.	710	1242	582	1067	0.15 (-)	0.16 (-)	1.52	1.21
19.	738	1242	508	932	1.04 (-)	2.67 (+)	1.65	1.09
20.	668	1256	667	1254	**18.03 (-)	14.09 (-)	1.73	1.15
Group :	**617**	**1532**	**588**	**1441**	**0.50**	**2.67**	**1.02**	**0.86**
	(152)	*(423)*	*(144)*	*(373)*	[0.24, 6.79]	[0.61, 12.54]	*(0.41)*	*(0.29)*

**: Steps were counted through half of the circuit only, because of technical difficulties with Fitbit® One;* **: Data considered as outliers in the statistical analysis; (-): when the monitor missed some steps; (+): when the monitor over-counted

Table 3: Occurrence of acceptable and unacceptable errors in step counting with Fitbit® One placed at the ankle (n = 19).

		Circuit		
		< 10%	> 10%	*Total*
6MWT	< 10%	12	5	*17*
	> 10%	0	2	*2*
	Total	*12*	*7*	***19***

6MWT: 6-minute walk test; 10%: acceptable threshold.