Predicting daily step activity

Timed walking tests correlate with daily step activity in individuals with stroke.

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Abstract

Objectives: The aim of this study was to examine the relationship between four clinical measures of walking ability and the outputs of the StepWatch Activity Monitor in participants with stroke.

Design: Correlational study

Setting: Clinic and participants' usual environments

Participants: 50 participants more than six months following stroke were recruited. Participants were all able to walk independently, but with some residual difficulty.

Interventions: Not applicable.

Main Outcome Measures: Rivermead Mobility Index (RMI), Rivermead Motor Assessment (RMA), Six Minute Walk Test (6MWT), 10 Metre Walk Test (10MWT), StepWatch outputs (based on daily step counts and stepping rates).

Results: The correlations between the RMA and all StepWatch outputs were low ($\rho=0.36$-0.48, $p<0.05$), as were the majority for the RMI ($\rho=0.31$-0.52, $p<0.05$). The 10MWT and 6MWT had moderate to high correlations ($\rho=0.51$ to 0.73, $p<0.01$) with the majority of StepWatch outputs. Multiple regression showed that the 6MWT was the only significant predictor for the majority of StepWatch outputs, accounting for between 38% and 54% of the variance. Age and the RMI were further significant predictors of one and two outputs respectively.

Conclusions: The 6MWT has the strongest relationship with the StepWatch outputs and may be a better test than the 10MWT to predict usual walking performance. However, it should be remembered that the 6MWT explains only half of the variability in usual walking performance. Thus, activity monitoring captures aspects of walking performance not captured by other clinical tests and should be considered as an additional outcome measure in stroke rehabilitation.

Key Words: Stroke; Ambulation; Activity

Stroke is the most common cause of severe disability in adults,[1] with persistent physical disability reported in 50-65% of individuals who survive stroke.[1-3] Although as many as 70% are able to walk independently following rehabilitation,[3, 4] it appears that only a small percentage of these individuals are able to walk functionally in the community.[5, 6] This difference may reflect a discrepancy between testing walking in a clinical environment and monitoring usual walking in natural environments as has been suggested by the International Classification of Functioning, Disability and Health. [7]

There are a range of clinical tests available to assess walking following stroke, many of which have good psychometric properties and assess wider aspects of gait thought to relate to walking in community environments.[8] Some tests involve direct therapist observation of walking, of which an aspect is then graded or measured. Examples include the Ten Metre Walk Test (10MWT),[9] the Six Minute Walk Test (6MWT)[10] and the Rivermead Motor Assessment (RMA).[11] Other outcome measures rely on patient self-report of usual function, such as the Rivermead Mobility Index (RMI)[12] and the Functional Ambulation Categories.[13]

The advantage of the directly observed tests is their standardized nature, but they may be more reflective of best performance rather than usual performance. For example, self selected gait speed (measured by the 10MWT) is a global indicator of physical functioning[14] and can discriminate between different categories of community ambulation.[6] However, community ambulation can be achieved by individuals with stroke who have low gait velocities suggesting that gait velocity alone is not sufficient as a measure of community ambulation.[6] Self report measures, on the other hand may ask about usual performance, however they depend on the accuracy of a patient's perception, cognition and communication.[15, 16] Indeed, a recent study has shown that individuals with stroke have a higher subjective report of physical activity and exercise than is found on objective testing.[17]

Activity monitors are one way of monitoring usual walking performance in natural environments as they can be worn during everyday activities over extended periods. The typical output is counts with respect to time, which can give information about amount, rate and patterns of activity. An activity monitor that has been used to investigate ambulatory activity following stroke is the StepWatch Activity Monitor[a].[18-20] The monitor contains a custom sensor that uses a combination of acceleration, position and timing to determine the number and rate of steps taken. The StepWatch has been shown to have criterion validity[18, 21] and is reliable[19, 22] for step counting in individuals with stroke. The output of the StepWatch is based on the number of steps taken on one leg, which is doubled to represent steps taken on both legs[19, 20, 23, 24]. The most commonly reported output of the StepWatch, mean steps per day,[19, 20, 23, 25] correlates moderately with self selected gait speed (r=0.55)[20] and scores on the Functional Independence Measure (r=0.62)[23] and Berg Balance Scale (r=0.58)[20] in patients with stroke. Recent research has also shown that mean steps/day shows a low correlation to peak exercise capacity (r=0.316)[24] but is not related to self-reported fatigue severity[24, 26] or economy of gait[24].

Many other outputs of the StepWatch are available, which include calculations based on rate of stepping. The peak activity index is the average step rate of the fastest 30 minutes over 24 hours, regardless of when they occurred. Sustained activity measures are also available for 1, 5, 20, 30 and 60 minutes and are calculated by scanning the accumulated 24 hour data to determine the maximum number of steps taken during continuous intervals of 1, 5, 20, 30 and 60 minutes. The number of steps at high (above 60 steps/min), medium (between 30 and 60 steps/min) and low (below 30 steps/min) step rates can also be calculated. We have recently shown good test-retest reliability for a number of these additional outputs in individuals with stroke, particularly peak activity index and maximum number of steps in 5 and 1 minutes.[22] However, the relationship between commonly used clinical measures of walking ability and these additional StepWatch outputs has not been studied.

Thus the aims of this study were to determine the strength of the relationship between commonly used clinical tests of walking ability and the available

StepWatch outputs and in particular, determine how well clinical walking tests predict ambulatory activity in natural environments as measured by the StepWatch. Self selected gait speed was measured by the 10MWT and gait endurance was measured by the 6MWT, both of which are used commonly [8] and have good psychometric properties.[10]

We chose the RMI to capture self reported mobility as six of the 15 items report on walking situations and it has good psychometric properties.[8] The Rivermead Motor Assessment (RMA) was also selected as five of the 13 items directly test walking conditions.[8] Both the RMI and RMA reflect a breadth of walking conditions, such as walking over uneven surfaces and walking outside that are not evaluated by the commonly used timed walking tests. We hypothesized that performance during these common walking conditions may have a stronger relationship to usual walking activity in natural settings than do the timed walking tests.

Methods

Participants

A power calculation based on mean steps/day (standard deviation of 4390 steps/day) and the 6MWT (standard deviation of 124 metres) from pilot data (n=16) suggested that a sample size of 24 would achieve 99% power (α=0.05)[27] for a single correlation. To ensure adequate power for a multiple regression analysis, a convenience sample of 50 individuals with chronic stroke was recruited based on formulae by Green (minimum of 46 participants for 5 predictors and estimated multiple correlation of 0.50).[28] Participants were recruited from the hospital stroke service and local and newspaper advertising and were eligible for inclusion if they were at least six months post stroke and were able to walk independently, but with some residual difficulty, confirmed by a score of less than 2 on at least one of the walking items (a, d, e, g, h, or i) of the physical functioning scale of the SF-36.[29] Participants also had to walk in the community at least once a week, determined by response to the question "How many times do you walk past your letterbox, on average in one week?" Individuals were excluded if they had fallen more than twice in the previous six months, had another serious health problem affecting walking (e.g. musculoskeletal or cardiovascular condition) or if they were unable to complete the testing for another reason (e.g. inability to follow instructions).

Testing Protocol

The study was approved by the Northern Regional Ethics Committee. All participants attended a rehabilitation clinic for initial testing and gave written informed consent. The clinical tests were administered by one examiner. The

RMI is a self report of ability to perform up to 15 mobility items, with answers given of either "yes" or "no". The highest score of 15 indicates an ability to climb up and down four steps with no rail and run 10 metres. The RMA was tested in a clinic and outside environment and patients were scored on each of the 13 items, based on their ability to perform the mobility task. The maximum score of 13 indicates an ability to run 10 metres and hop on the affected leg five times. Self selected gait speed was measured at comfortable pace over 10 metres (10MWT) and gait endurance was tested by the 6MWT, both following standardised protocols.[30]

A StepWatch was calibrated and attached to the lateral side of the ankle of the non-paretic leg with a strap or cuff. The monitor has an infrared light that flashes with every step, which were matched to a manual count of steps during walking five metres at each of three walking speeds (fast, slow and self selected). The sensitivity and cadence settings were adjusted, if necessary, until the flashes corresponded exactly with the manual count during the three walking speeds.

Participants were instructed to wear the monitor for the next three days, removing it for sleeping and showering. Participants were given an instruction sheet with details about the care of the StepWatch and a follow up appointment was made to pick up the monitor. Data were exported to Excel[b] where the number of steps detected over a 24 hour period was doubled to obtain steps/day for both legs. A sub-group of these patients (n=37) also agreed to participate in further data collection for a larger study of reliability testing, results of which are in press.[22]

Statistical analyses

Variables were tested for normality using the Shapiro-Wilk statistic. The level of association between the variables was assessed using Pearson's correlation coefficient for normally distributed variables or Spearman's rank correlation coefficient for variables without a normal distribution, with significance accepted at the 0.05 level. A correlation above 0.90 was interpreted as very high, 0.70-0.89 as high, 0.50-0.69 as moderate, 0.30-0.49 as low and less than 0.29 as little, if any correlation.[31] Age and gender were also tested for correlation with StepWatch outputs as they were potentially confounding factors. A forward linear multiple regression analysis was performed for each of the significant variables from the correlation entered as independent variables and the StepWatch outputs as the dependent variables. All calculations were performed using SPSS.[c]

Results

Fifty participants enrolled in the study. Forty-nine of the 50 participants, mean ± SD age of 67.4 ± 12.5 years and six to 219 months following stroke, completed the study (Table 1). The remaining participant did not have three complete days of data so was excluded from the analysis. There were 29 men and 20 women. Eighteen participants had right sided paresis. The median score on the physical functioning index of the SF-36[29] was 18 (range 10 to 29), where the maximum score of 30 indicates no limitations with all items, including walking more than a mile, climbing several flights of stairs and running and a score of 10 indicates significant limitations with all items. All participants walked independently with an assistive device, if necessary. However, median scores on the RMI and RMA indicated that the participants had difficulty with higher level mobility tasks such as running, hopping and climbing up and down steps without a handrail. The mean steps/day showed a wide variation between participants from a low of 1225 steps/day to a high of 21273 steps/day (Table 1). However, the median of 4765 steps/day in this study was lower than 6565 steps/day reported by Bohannon[32] for apparently healthy adults over 65 years.

Only two clinical tests (10MWT and 6MWT) and three StepWatch outputs (number of steps at a low rate, peak activity index and highest step rate in 1 minute) were distributed normally. Thus, the majority of correlations shown in Table 2 use Spearman’s correlation coefficient. Gender showed no correlation with any of the StepWatch outputs but age showed a significant but low correlation ($\rho=-0.33$, $p<0.05$) with number of steps at a high rate and highest step rate in 60 minutes. The correlations between the RMA and all the

StepWatch outputs were less than 0.50, as were the majority for the RMI. There were two moderate correlations between StepWatch outputs and the RMI; mean steps/day was positively correlated ($\rho=0.51$, $p<0.01$) and percentage of time with no steps was negatively correlated ($\rho=-0.52$, $p<0.01$). The 10MWT had moderate correlations with the majority of StepWatch outputs, with the highest step rate in one minute reaching a high level of correlation ($r=0.71$, $p<0.01$). The 6MWT reached at least a moderate level of correlation with all StepWatch outputs, with peak activity index ($r=0.72$, $p<0.01$) and highest step rate in one minute ($r=0.73$, $p<0.01$) reaching a high level of correlation.

Regression analysis using StepWatch outputs as the dependent variables and age, RMI, RMA, 10MWT and 6MWT as the independent variables showed that for the majority of StepWatch outputs, the 6MWT was the single most significant predictor (Table 3). The 6MWT accounted for between 30% (for number of steps at a low rate) and 54% (for mean steps/day) of the variance in the StepWatch outputs. For three outputs (highest step rate in 60 minutes, percentage of time with no steps and number of steps at a low rate), other variables made an independent contribution to the variance. Age made a significant contribution to the variance in highest step rate in 60 minutes over and above that of the 6MWT, increasing the explained variance from 44% to 49%. The 6MWT and the RMI independently contributed to both the percentage of time with no steps and the number of steps at a low rate. For the percentage of time with no steps, the addition of RMI increased the explained variance from 40% to 47%. For the number of steps at a low rate, the addition of the RMI increased the explained variance from 30% to 36%.

Discussion

The aims of this study were to determine the strength of the relationship between commonly used clinical tests of walking ability and the available StepWatch outputs and in particular determine how well clinical walking tests predict ambulatory activity in natural environments. We found that both the 10MWT and the 6MWT were, in general, more highly correlated with the StepWatch outputs than were either the RMI or the RMA. However, on regression analysis, the 6MWT was the only significant predictor for all but three of the StepWatch outputs, with the 10MWT making no further independent contribution to the variance.

The 6MWT is seen as a measure of submaximal exercise performance.[33] Thus, the ability of the 6MWT to predict variations in walking performance in a natural environment is perhaps not unexpected. It is possible that distance on the 6MWT could be used as a quick test to estimate usual walking activity. From our data, the 95% confidence interval for the regression equation for an individual who achieved a distance of 153 metres would suggest that they might average between 3078 and 5231 steps/day.

Self selected gait speed measured over a short distance (eg 10MWT) is the most commonly used test to assess walking ability in a clinical situation.[8] It is extremely quick and easy to administer, and from both this study and others[20, 34] is moderately correlated to mean steps/day, both in participants with stroke (r=0.55)[20] and neurological disorders (r=0.58).[34] However, our data suggests that the 6MWT may be a better clinical test to use to predict usual walking performance. The 10MWT nevertheless is very highly correlated with the 6MWT and still has a role, particularly if it is not possible to test walking for six minutes.

Both the RMI and RMA showed a low correlation with the majority of StepWatch outputs. These data are similar to a previous study of participants with neurological disorders which showed a low correlation between mean steps/day and the RMI (r=0.49).[34] One explanation for this finding is that both the RMI and the RMA assess mobility, rather than walking per se. For example, they both assess bed mobility and transfer skills. They also assess wider aspects of walking, such as stair climbing, walking outside and walking over uneven surfaces, which are thought to be important aspects of usual walking performance.[35] Although the StepWatch accurately identifies steps under these walking conditions,[21] it does not distinguish between these different aspects of walking, which might explain the lower correlation.

However, the RMI, which measures self reported mobility, was an independent predictor of two StepWatch outputs (percentage of time with no steps and number of steps at a low stepping rate). Both of these outputs reflect reduced levels of walking activity. This result suggests that patients' perception of reduced mobility may be able to predict aspects of usual walking performance. Although, self reported measures of physical activity have been shown to be inflated when compared to mean steps/day,[17] it is still possible that some individuals with stroke voluntarily restrict activity if they have a low perception of their functional ability.[36] However, whether the perception of reduced mobility is a causative factor in the low levels of activity or a consequence of it, is not certain.

In addition to the 6MWT, age was an independent predictor of, and inversely related to, the highest step rate in 60 minutes. This StepWatch output measures the highest step rate in a continuous 60 minute period and might be expected to decrease with reduced exercise performance, as measured by the 6MWT.[37] However the finding that age also makes an independent contribution was unexpected as age has not been shown to relate to walking speed in adults with chronic stroke.[38] This finding suggests that the level of sustained activity decreases with age in people with chronic stroke over and above that which can be attributed to decreased endurance.

Half of the variability in StepWatch outputs of usual walking performance is not accounted for by the clinical walking tests. As community walking is related to other physical characteristics in addition to gait speed,[6, 39] it is also possible that physical factors such as balance,[40] fitness,[41] use of assistive devices and motor function may also affect usual walking performance. It is also likely that behavioural, personal, environmental and social factors will have some impact on walking performance in natural environments,[14, 42] but there is little research in this area. Until these factors are identified, there would seem to be a place for the inclusion of activity monitoring as an outcome measure during stroke rehabilitation.

Limitations of this study are the selected nature of the participants, which may not generalize to the entire stroke population. Furthermore, participants may have changed their walking activity in their own environment as a result of the monitoring, thus not giving completely accurate data on usual performance.

In addition, this study was adequately powered to detect a correlation coefficient $r>0.5$ in the regression analysis, but more subjects would have been needed to detect a smaller effect size[28], such as shown by the lower correlations between both the RMI and the RMA and the SAM outputs. However, the question remains, whether such a level of correlation should be considered to be clinically significant.

It should be acknowledged that while the StepWatch is an objective measure of usual walking, the information gained is limited to amount and rate of walking and patterns of activity. The StepWatch cannot, for instance, give information about functional goals achieved or effectiveness and energy cost of walking.

Conclusions

The 6MWT is the clinical test with the strongest relationship with the StepWatch outputs. Thus the 6MWT may be a better test than the 10MWT to predict usual walking performance, however, it should be remembered that half of the variability in usual walking performance is not explained by either clinical walking test. Thus, activity monitoring detects aspects of usual walking performance in participants with stroke not captured by clinical tests and should be considered as an additional outcome measure for rehabilitation programmes.

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Suppliers

a. Orthocare Innovations, 6405 218th St SW, Suite 100, Mountlake Tce, WA 98043-2180, US

b. Excel 2003. Microsoft Corporation, One Microsoft Way, Redmond, WA 98052-7329, US

c. SPSS Inc. Headquarters, 233 S. Wacker Drive, Chicago, IL 60606, US (Version 14.0.0)

Table 1. Study Sample Characteristics

	Mean ± SD	Median	Range
Demographics			
Age (years)	67.4 ± 12.5		38 - 89
Months since stroke	66 ± 61		6 - 219
SF-36 score		18	10 - 29
Clinical Test			
10MWT (m/s)	0.67 ± 0.32		0.12 - 1.42
6MWT (m)	230 ± 121		42 - 568
RMA		10	5 - 13
RMI		13	6 - 15
StepWatch Outputs			
Mean steps/day		4765	1225 - 21273
Percentage of time with no steps (%)		83%	53 - 96
Number of steps at low rate (<30 steps/minute)	2334 ± 565		493 - 5331
Number of steps at high rate (>60 steps/minute)		655	0 - 10590
Peak activity index (steps/min)	58.7 ± 10.6		17 - 112
Highest step rate in 60 minutes (max 60) (steps/min)		18.7	5 - 89
Highest step rate in 1 minute (max 1) (steps/min)	81.5 ± 11.1		23 - 128

Table 2. Correlation coefficient* for StepWatch outputs and clinical gait tests and age.

StepWatch output	RMI	RMA	10MWT	6MWT	Age
Mean steps/day	0.51	0.47	0.55	0.67	-0.29†
Percentage of time with no steps	-0.52	-0.47	-0.41	-0.57	NS
Number of steps at low rate (<30 steps/minute)	0.47	0.44	046*	0.58*	NS
Number of steps at high rate (>60 steps/minute)	0.31†	0.42	0.54	0.60	-0.33†
Peak activity index	0.37	0.40	0.64*	0.72*	-0.28†
Highest step rate in 60 minutes (max 60)	0.46	0.48	0.51	0.59	-0.33†
Highest step rate in 1 minute (max 1)	0.36†	0.41	0.71*	0.73*	NS

* indicates use of Pearson's correlation coefficient. All other correlations use Spearman's correlation coefficient.
† correlation is significant at the 0.05 level. All other correlations are significant at the 0.01 level.
NS = not significant

Table 3. Stepwise linear regression models of selected StepWatch outputs

StepWatch Output/Predictors	**Regression coefficients**	**R^2**	**R^2 change**	***p***	**adjusted R^2**	**constant**
Mean steps/day						
6MWT	26.2	0.54		0.000	0.53	159.7
Percentage of time with no steps (%)						
6MWT	0.000	0.40		0.000	0.38	0.92
6MWT & RMI	0.000 / -0.014	0.46	0.06	0.000	0.44	1.07
Number of steps at low rate (<30 steps/minute)						
6MWT	5.39	0.33		0.000	0.32	1092
6MWT & RMI	3.92 / 186.5	0.41	0.08	0.000	0.39	-908.4
Number of steps at high rate (>60 steps/minute)						
6MWT	12.2	0.46		0.000	0.45	-625.5
Peak activity index (steps/min)						
6MWT	0.126	0.51		0.000	0.50	29.7
Highest step rate in 60 minutes (max 60) (steps/min)						
6MWT	0.090	0.44		0.000	0.43	4.05
6MWT & Age	0.082 / -0.312	0.49	0.05	0.000	0.47	26.6
Highest step rate in 1 minute (max 1) (steps/min)						
6MWT	0.136	0.54		0.000	0.53	50.3