How Active Are People With Stroke?
Use of Accelerometers to Assess Physical Activity

Debbie Rand, PhD, OT; Janice J. Eng, PhD, PT/OT; Pei-Fang Tang, PhD, PT; Jiann-Shing Jeng, MD, PhD; Chihya Hung, MSc, PT

Background and Purpose—Accelerometers are a unique tool used to objectively measure free-living physical activity, but their reliability for people with stroke has not been established. The primary aim was to assess the day-to-day reliability of these instruments for the paretic and nonparetic hips. The secondary aims were to measure the amount of physical activity with accelerometers that people with stroke undertake in the community and its relationship with walking capacity (6-minute walk test distance).

Methods—Forty people with stroke wore one Actical accelerometer on each hip for 3 consecutive days at home and during the 6-minute walk test in the laboratory. The accelerometer measured physical activity using total activity counts per day and energy expenditure (kcal/d).

Results—Excellent intraclass correlation coefficients (ICCs) for the activity counts (paretic hip ICC_{1,3}=0.94, nonparetic hip ICC_{1,3}=0.94) and for the energy expenditure (paretic hip ICC_{1,3}=0.95, nonparetic hip ICC_{1,3}=0.95) were found across the 3 consecutive days at home. Excellent ICCs were also found between the paretic versus the nonparetic hips for the activity counts (ICC_{1,3}=0.98) and for the energy expenditure (ICC_{1,3}=0.96). Free-living physical activity was very low and 58% of the participants did not meet recommended physical activity levels. Only moderate correlations (r=0.6 to 0.73, P<0.001) were found between the 6-minute walk test distance in the laboratory and 3-day physical activity recording at home.

Conclusions—The accelerometer was found to be a reliable objective instrument. The use of accelerometers quantified the low level of free-living physical activity of people with stroke. (Stroke. 2009;40:000-000.)

Key Words: accelerometers ■ community-dwelling ■ physical activity ■ stroke

Assessing walking and other physical activities of people with chronic conditions outside the laboratory is essential. There have been recent innovations to capture this measure in the general population.1 Accelerometers worn on the hip provide real-time estimates of the frequency, intensity, and duration of physical activity.1,2 Although pedometers are also a tool for monitoring physical activity, these tools simply count the number of steps taken per day.1,3,4 The accelerometers, on the other hand, provide measures of physical activity intensity through activity counts. Activity counts can then be converted to energy expenditure.2 Thus, accelerometers cannot only differentiate between walking slowly versus briskly, but also account for other common movements involved in daily activities of living such as rising from a chair.5 Although physical activity can be captured by self-report questionnaires, Hagstromer et al1 revealed that values of physical activity obtained by real-time accelerometers in 1114 healthy adults (ages 18 to 69 years) were much lower than that from self-report recall.

Although some psychometric properties of accelerometer measures to capture real-time free-living physical activity have been established for healthy adults, they have not been established for people living with stroke in the community. Reliability is the degree to which measurements are free from error and is a prerequisite to establishing validity or using an instrument as an outcome measure.6 Excellent test–retest reliability of the accelerometer has been found for 20 young adults for different treadmill speeds (intraclass correlation coefficient [ICC]=0.87 to 0.92)7 and for 40 older adults (mean age 76 years) for sitting and treadmill walking (ICC=0.97).8 Welk9 assessed the test–retest reliability of 4 different types of accelerometer monitors while college students completed 3 5-minute bouts of treadmill walking (3 mph). The ICCs ranged from 0.62 to
0.80 for all 4 types of monitors. Although the reliability of treadmill bouts has been established, no study has assessed the reliability of accelerometers for free-living physical activity (all the wake hours) between separate days for healthy populations.

Different models of accelerometers have been compared in healthy populations over several days and between the right and left hips. Paul et al evaluated the correlation between 2 types of accelerometers (Actigraph and Actical) with 56 healthy subjects (aged 30 to 60 years) who wore the monitors for 15 days. They found that both activity monitors predict physical activity and a conversion equation can be used to compare the readings from the 2 models. Thus, although there is some variability between the models, accelerometers are a reliable tool to monitor physical activity in healthy populations. Furthermore, it does not appear to matter which hip the accelerometer is worn on for healthy adults because excellent reliability (ICC = 0.73 to 0.76) has been found between the right and left hips of 20 young adults for different treadmill speeds and for 10 young adults (ICC > 0.97) over 24 hours.

However, the psychometric properties of studies with healthy populations cannot be generalized to people with stroke because they walk slowly and their gait is typically asymmetrical with abnormal gait biomechanics. A limited number of studies have used accelerometers to assess physical activity in populations that may demonstrate gait impairments. Haeuber et al used a mechanical accelerometer (Caltrac) located on the nonparetic side to estimate the total activity counts and energy expenditure. They found the Caltrac accelerometer to have poor test–retest reliability (ICC = 0.44) during 2 separate 24-hour periods of free-living physical activity in 17 people with chronic stroke aged 65 ± 6 years. However, the Caltrac is a uniaxial accelerometer and may not capture the altered gait movements that are known to occur in nonsagittal planes. Motl et al assessed the physical activity of 193 subjects (mean age 46 years) with multiple sclerosis with an Actigraph accelerometer worn on the hip for 7 days and reported good ICC reliability over 3 days (0.80) and 7 days (0.93). They found no difference in physical activity between days in the week or weekends.

Accelerometers are a unique tool to objectively measure real-time free-living physical activity. The reliability of these monitors for people with stroke has not been well established and it is unknown whether there are differences between measures when worn on the paretic or nonparetic hips. We proposed to evaluate the use of accelerometers worn on both hips of people living with stroke for monitoring free-living physical activity. Our primary aim was to assess the reliability of accelerometers (1) across the 3 consecutive days for both hips; and (2) between accelerometers worn on the paretic versus the nonparetic hip. Our secondary aims were (1) to measure the amount of physical activity over 3 days; and (2) to determine the relationship of activity recorded during a laboratory-based measure of walking capacity (6-minute walking test) to that of free-living activity in the community. The 3-day period was chosen because a minimum of 3 days has been shown to achieve reliability of 0.80 for pedometer measures in healthy adults and for accelerometer measures in patients with multiple sclerosis.

**Methods**

**Participants**

Forty adult community-dwelling people with stroke volunteered to participate in the study. Participants were recruited through the local hospital stroke registry database. This study was approved by the local university ethics board, and all eligible subjects gave written informed consent before participating in the study. The diagnosis of the stroke was made by a neurologist based on both clinical characteristics and neuroimaging findings. All subjects were assessed by at least one brain imaging modality (CT or MRI). The inclusion criteria included: had a single unilateral stroke at least 6 months ago, living in the community, and had the ability to walk with or without a walking device. Exclusion criteria included: (1) unstable medical condition; (2) chest pain, heart attacks, angioplasty, or heart surgery in the previous 3 months; and (3) significant neurological or musculoskeletal problems from other than stroke. The Chedoke-McMaster Stroke Assessment was used to measure and determine the presence and severity of leg, foot, arm, and hand physical impairments. The Chedoke-McMaster Stroke Assessment has good concurrent validity with the Fugl-Meyer Assessment of Sensorimotor Recovery and moderate correlations with burden of care and activities of daily living (Barthel Index).

**Accelerometer Measures of Physical Activity**

Accelerometers were used to measure participation in physical activity in the real world setting. The Actical (Mini-Mitter Co) accelerometer was used to obtain measurements. The Actical was selected because it is a triaxial, waterproof accelerometer and has been found to be superior to 2 other commonly used accelerometers (Actigraph and RT3) for intrainstrument and interinstrument reliability. Heil found the Actical to predict activity energy expenditure, which is the relative energy expenditure (kcal/kg per minute) to perform a task above the resting metabolism. His study included children and young adults undertaking 10 different activities such as floor sweeping and treadmill walking.

The Actical accelerometer is a small (28X27X110 mm), lightweight (17 g) sensor, which has a frequency range of 0.3 to 3 Hz, is sensitive to 0.05 to 2.0 G force, and samples at 32 Hz. It detects acceleration in all 3 planes, although it is more sensitive in the vertical direction. Data are rectified, integrated, and then stored as activity counts every 15 seconds (epoch); the count data in each epoch represents the intensity of the activity performed. Data were expressed as total activity counts per day and the total energy expenditure per day (kcal/d). The accelerometer detects low-frequency G forces common to human movement. Our own experience is that the accelerometer is sensitive to movements, including large movements (transfers) as well as small movements of the trunk (shifting weight while sitting). However, because the accelerometer is worn on the hip, if the person simply taps their foot while sitting, no activity counts are generated.

**Procedure**

The participants wore an elastic belt with 2 small Actical monitors positioned over the anterior–superior iliac spine for 3 consecutive days and were instructed to go about their normal lives. Within the laboratory, participants performed the 6MWT with the accelerometers in which participants walked as far as they could for 6 minutes with their usual assistive device (eg, cane). This distance is a measure of functional capacity because it requires a reasonable level of physical activity over a time period that may be associated with activities of daily living. The 6MWT was administered twice (once when the accelerometers were initially provided and 4 days later when the subjects returned the accelerometers). The results from the second test were analyzed because the first assessment is considered necessary for practice.
Table 1. Demographic and Stroke Characteristics of the Study Population (N=40)

<table>
<thead>
<tr>
<th></th>
<th>Mean±SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td>66.5±9.6</td>
<td>49–82</td>
</tr>
<tr>
<td>Years poststroke</td>
<td>2.9±2.4</td>
<td>1–12</td>
</tr>
<tr>
<td>Body mass index, kg/m²</td>
<td>24.3±3.6</td>
<td>16.3–34.3</td>
</tr>
<tr>
<td>Mini-Mental State Exam</td>
<td>27±3</td>
<td></td>
</tr>
<tr>
<td>Gender, men/women</td>
<td>13/27</td>
<td></td>
</tr>
<tr>
<td>Side of cerebrovascular accident, right/left</td>
<td>20/20</td>
<td></td>
</tr>
<tr>
<td>Ischemic/hemorrhage</td>
<td>37/3</td>
<td></td>
</tr>
<tr>
<td>Leg impairment severe/moderate/mild*</td>
<td>1/2/37</td>
<td></td>
</tr>
<tr>
<td>Foot impairment severe/moderate/mild*</td>
<td>5/1/34</td>
<td></td>
</tr>
<tr>
<td>Arm impairment severe/moderate/mild*</td>
<td>4/2/34</td>
<td></td>
</tr>
<tr>
<td>Hand impairment severe/moderate/mild*</td>
<td>5/1/34</td>
<td></td>
</tr>
<tr>
<td>Walking aid (cane), yes/no</td>
<td>15/25</td>
<td></td>
</tr>
</tbody>
</table>

*Chedoke-McMaster Stage of Motor Recovery: severe/moderate/mild motor impairment in which severe=1 to 3 out of 7 points, moderate=4 to 5 out of 7 points, mild=6 to 7 out of 7 points.

Results

The demographic information of the population is presented in Table 1. Fourteen participants wore the accelerometers during weekdays only, whereas the wearing time for 26 participants included a weekend. The accelerometer activity and the energy expenditure (for each hip) over the 3 days appear in Table 2. Paired t tests between the daily weekday (mean±SD 30,973±36,514 activity counts) and the weekend activity (29,354±33,949 activity counts) for those participants who wore the accelerometer over the weekend revealed no significant differences. The participants wore the accelerometers for an average of 15±1.8 hours a day with wearing time ranging from 10 to 18 hours a day. The participants spent 13±2 hours a day (out of their wake hours) without hip movements in which the accelerometer on the hip recorded zero activity counts per minute.

Excellent ICCs with narrow CIs for the activity counts and for the energy expenditure were found for the 3 consecutive days at home for both the paretic (ICC[1,3]>0.95) and nonparetic hips (ICC[1,3]>0.94; Table 3). Excellent ICCs between the paretic versus the nonparetic hips were also found for the activity counts (ICC[1,3]=0.94 to 0.99; 95% CI, 0.94 to 0.99) and energy expenditure (ICC[1,3]=0.95 to 0.96; 95% CI, 0.91 to 0.97) for 3 days. In addition, the analysis of variance found no difference between the paretic and nonparetic hip values. Smaller SEM% and MDC% values reflect lower measurement errors and greater responsiveness as compared with higher SEM% and MDC% values (Table 3).

The distance walked during the 6MWT was 318.8±78.6 m and 15 of the subjects used a cane for walking. The accelerometers were also worn while the participants completed the 6MWT. The mean total activity count for the paretic hip during the 6MWT was 9000±6169 and 9574±6760 activity counts for the nonparetic hip.

Strong significant correlations were found between the distance walked in 6 minutes to the activity counts registered on the paretic hip (r=0.89, P<0.001) and nonparetic hip (r=0.98, P<0.001) during the 6MWT. Moderate significant correlations were found between the distance walked in 6 minutes to the activity counts registered on the paretic hip (r=0.67, P<0.001) and nonparetic hip (r=0.73, P<0.001) during 3 days at home.

Table 2. Accelerometer Activity Counts and Energy Expenditure (kcal/day) Recorded From the Paretic and Nonparetic Hips (mean±SD; N=40)

<table>
<thead>
<tr>
<th></th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Mean of 3 Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paretic hip</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity counts</td>
<td>54,079±86,790</td>
<td>60,034±92,944</td>
<td>48,393±87,039</td>
<td>55,886±5696</td>
</tr>
<tr>
<td>Energy expenditure</td>
<td>157.8±154.2</td>
<td>188.5±159.8</td>
<td>142.0±152.2</td>
<td>163.1±149.4</td>
</tr>
<tr>
<td>Nonparetic hip</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity counts</td>
<td>52,286±90,179</td>
<td>60,097±87,934</td>
<td>46,842±84,627</td>
<td>53,075±83,476</td>
</tr>
<tr>
<td>Energy expenditure</td>
<td>154.6±150.2</td>
<td>179.3±152.9</td>
<td>133.9±138.3</td>
<td>155.9±140.7</td>
</tr>
</tbody>
</table>
Table 3. Relative (ICC) and Absolute Reliability (SEM, MDC) of the Accelerometers for Day-to-Day Free-Living Physical Activity Over 3 Days (N=40)

<table>
<thead>
<tr>
<th></th>
<th>ICC</th>
<th>95% CI</th>
<th>SEM*</th>
<th>SEM%*</th>
<th>MDC*</th>
<th>MDC%*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paretic hip</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity counts</td>
<td>0.95</td>
<td>0.92–0.97</td>
<td>18 324</td>
<td>32.78</td>
<td>50 792</td>
<td>90.88</td>
</tr>
<tr>
<td>Energy expenditure</td>
<td>0.95</td>
<td>0.92–0.97</td>
<td>31.38</td>
<td>19.28</td>
<td>86.98</td>
<td>53.44</td>
</tr>
<tr>
<td>Nonparetic hip</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity counts</td>
<td>0.94</td>
<td>0.91–0.97</td>
<td>17 690</td>
<td>33.33</td>
<td>49 035</td>
<td>92.38</td>
</tr>
<tr>
<td>Energy expenditure</td>
<td>0.95</td>
<td>0.90–0.96</td>
<td>32.26</td>
<td>20.69</td>
<td>89.42</td>
<td>57.34</td>
</tr>
<tr>
<td>Paretic versus nonparetic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity counts</td>
<td>0.98</td>
<td>0.97–0.99</td>
<td>9755</td>
<td>17.90</td>
<td>27 039</td>
<td>49.63</td>
</tr>
<tr>
<td>Energy expenditure</td>
<td>0.96</td>
<td>0.93–0.98</td>
<td>27.63</td>
<td>17.32</td>
<td>76.58</td>
<td>48.01</td>
</tr>
</tbody>
</table>

*SEM and MDC in units of activity counts or kcal for energy expenditure.

Discussion

The accelerometer provided an accurate and reliable measure of day-to-day free-living physical activity level of people with stroke living in the community. There was excellent day-to-day reliability between the 3 consecutive days (ICC >0.94; 95% CI, 0.91 to 0.97) and acceptable measurement error (SEM% = 19.3% to 30.8%). These findings are consistent with the 3-day reliability (ICC = 0.80) found for people with multiple sclerosis and substantially higher when using an uniaxial accelerometer between 2 days (ICC = 0.44) for people with stroke. McClain et al argued that it was not realistic to assess reliability of activity in the free-living environment because most people vary their routine from day to day. The low between-day variability found in our study indicates that the participants may have a routine with similar core activities each day. Because all of the participants were retired, the day-to-day activity may have been more consistent and we found no differences between weekdays and weekend activity. In addition, besides wearing the belt in the prescribed manner for all the wake hours, no other parameters of the accelerometer needed to be changed or adjusted by the subject. The data are downloaded and analyzed by the Actical software, which is also not dependent on any subjective analyses.

As expected, our absolute reliability estimates are higher than the 10% SEM for test–retest reliability of clinical gait and balance measures of persons with chronic stroke because those are measures performed with specific tasks under precise instructions. This contrasts with our accelerometer measures in which we instructed participants “to go about their normal lives” over 3 days. Nevertheless, our SEM estimates for the activity counts and energy expenditure are similar to those reported in persons with hemiparesis for other typical instrumented measures such as grip strength (20%) and for an upper limb trajectory-tracking task (24% to 36%).

It is well recognized that people with stroke walk slowly and that their gait is typically asymmetrical with abnormal gait biomechanics. Regardless of this fact, excellent ICCs (>0.96) were found between the reading of the accelerometer located above the paretic hip versus the accelerometer located above the nonparetic hip and no significant differences were found between paretic and nonparetic hip values. The high ICCs in part reflect the mechanical link between the 2 accelerometers, which are placed on either side of the rigid pelvis segment. Some components of acceleration (eg, forward acceleration) will be similar between the 2 sides when the whole body mass is moving forward while walking. Therefore, in future studies, it is sufficient to use one accelerometer located on either hip to record the free-living activity of this population.

Our sample represents people with a mild motor impairment after a stroke; a mean 318.8 m 6MWT translates to a gait speed of 0.89 m/s, which is sufficient to meet the highest level of walking category in people with stroke (eg, independent in all home and community activities, complete independence in shopping centers). In addition, participants had a median of 7 on the physical impairment scores, which is the highest stage of motor recovery. However, our sample of people with mild motor impairment still had substantial limitations compared with healthy individuals; 318.8 m during the 6MWT is 36% less than normative 6MWT values from 4809 community-dwelling individuals aged 60 years or older (mean of 499 m; range, 480 to 519 m). A distance <400 m within 6 minutes has been associated with higher risk of mortality.

The energy expenditure from the accelerometers revealed concerning findings; most of these community-dwelling participants with mild motor impairment after stroke do not meet the recommended level of physical activity. The recommended intensity of physical activity for adults is above 1000 kcal/week (142 kcal/d), possibly reaching 1500 to 2000 kcal/week (215 to 285 kcal/d), including at least 30 minutes of exercise a day. These intensities are important for reducing morbidity and preventing the development of secondary chronic diseases. Twenty-two participants (58%) did not reach 142 kcal/d, 9 participants (27%) used between 142 and 285 kcal/d, whereas only 4 participants (18%) used more than 286 kcal/d. Reduced activity after stroke can lead to disuse atrophy and cardiovascular deconditioning and subsequent loss in the functional gains achieved during rehabilitation. In particular, people with stroke are at high risk of cardiovascular disease and recurrent stroke, and regular physical activity is one lifestyle modification recommended to reduce the risk of these conditions.
In addition to energy expenditure, the activity counts can also be used to demonstrate the lack of activity of our sample. The algorithms used to calculate energy expenditure are based on healthy individuals. People living with stroke may have higher energy costs while ambulating. Therefore, it is also useful to examine the raw activity counts and conversion formulas that have been validated between Actical and Actigraph data. During the 3-day collection, our participants with stroke had a mean 62.8 ± 90.4 activity counts/minute recorded over the paretic hip. Our own database of 40 healthy older adults (mean age 71.3 ± 3.8 years) had a mean activity count per minute of 150 ± 75 (unpublished data from 7-day accelerometer hip recording), which is over double that of the participants with stroke. McClain et al classified those below a threshold of 435 Actical-converted activity counts/minute as sedentary in healthy young adults. Ham et al reported a mean of 721 Actical-converted activity counts/minute for 12 healthy subjects aged 22 to 56 years over 7 consecutive days while Hagstromer et al reported 323 ± 120 Actical-converted activity counts/minute for 1114 subjects (mean age 44.5 ± 14 years). In fact, our finding of 62.8 activity counts/minute translates to the physical activity recorded during sitting activities (12 to 77 activity counts/minute). Despite the fact that the population in the current study is older than that found in the literature, the disparity between the activity counts of our participants and the other populations is vast, emphasizing the fact that the people with stroke in the current study had low activity levels.

Despite sufficient ability to walk within the laboratory, many individuals demonstrated low levels of physical activity at home. Only moderate correlations were found between the distance walked during the 6MWT (measure of walking capacity under ideal conditions) and the activity counts during the 3 days at home (measure of participation in physical activities). This relationship is presented graphically in the Figure in which despite the fact that some people do have the ability to walk a considerate distance in the 6MWT (eg, >400 m), they do not use this potential to engage in physical activity. Thus, a number of subjects have a high 6MWT and low 3-day activity count. This observation is similar to the phenomenon of upper extremity “learned nonuse” described in an article appropriately titled “Stroke Recovery; He Can But Does He?” These subjects with stroke demonstrated the ability to use the arm in the clinic setting but did not use their arm at home. Clinicians should be aware that even people with stroke who have mild motor impairment present a low level of physical activity and should be encouraged to counsel these individuals to engage in leisure, sport, and fitness programs that enhance physical activity. There is preliminary evidence that physical activity counseling can increase physical activity behavior and participation in community-dwelling people with stroke.

Several limitations of this study should be acknowledged. The results can only be generalized to stroke participants with mild motor impairment who are community-living. Energy expenditure conversions were based on healthy norms, which may underestimate the energy cost of people with stroke; however, the low level of physical activity of our participants was also demonstrated using the raw activity counts. The accelerometer records activity due to multiple short bouts or less frequent but larger bouts. Unfortunately, to date, there are no established thresholds that could be used to differentiate between these types of activities, which may have different health benefits. However, future research will hopefully establish these guidelines.

Conclusions
This study assessed the day-to-day reliability of the Actical accelerometer and found it to be a reliable objective measure to determine the level of free-living activity in people with stroke. It was revealed that this community-dwelling sample of people living with stroke was very inactive. Accelerometers could be used as an outcome measure to determine whether rehabilitation promotes community reintegration in
terms of physical activity. Further research could investigate uses of accelerometers to monitor and increase free-living physical activity in community-dwelling people living with stroke.

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Disclosures

None.

References

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