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Title: Utility of a Unilateral Accelerometer for Monitoring Upper Extremity Use in Subacute Stroke Patients after Discharge from Hospital

Abstract

The objectives of this study were to investigate the utility of a unilateral accelerometer, which is commonly used for monitoring upper extremity performance in subacute stroke patients by comparing its use with other upper extremity functional assessments. Twenty-four participants were recruited and required to wear an accelerometer on the affected wrist for 3 hours a day for the first 4 weeks after discharge from hospital. Assessments included Fugl-Meyer Assessment–Upper Extremity (FMA-UE), Action Research Arm Test (ARAT), Box and Block Test (BBT), and self-reporting Motor Activity Log (MAL). Assessments were made at 0-, 4-, 8-, and 12-weeks after hospital discharge. How long the device was worn, movement amount, and movement percentage, were extracted from the accelerometer. Throughout the 12-week observation, significant improvements in the participants were shown by the FMA-UE, ARAT, and BBT ($p<0.001$, $p=0.026$, and $p<0.001$, respectively); but no significant change could be found using MAL or the accelerometer parameters across time ($p=0.068$ to $p=0.999$). There was moderate to good correlation among the assessment measures; however, no significant correlation was obtained between any of the assessments and the accelerometer data. These results suggest that the unilateral accelerometer might not be useful to reflect actual arm functions in daily activities.

Keywords: stroke, paretic upper extremity, learned non-use, accelerometer

Introduction

The phenomenon of learned non-use is quite common in stroke patients and affects their motor recovery (Taub et al., 1993). Even in-patients who receive intensive rehabilitation and are reminded regularly by healthcare professionals to use their more-affected upper extremities are more likely to employ their less-affected ones (Narai et al., 2016); thus, it is unsurprising that in an unsupervised environment, chronic stage stroke patients rely more on their less-affected upper extremities in daily life (Bailey et al., 2015).

Monitoring the frequency of upper extremity use helps healthcare professionals to assess stroke patients' compliance and self-efficacy in overcoming learned non-use outside of rehabilitation settings. In a previous study, the Motor Activity Log (MAL) – a subjective self-report questionnaire – was developed to evaluate learned non-use (Uswatte et al., 2006). On these questionnaires stroke patients are required to rate their performance (of 30 daily activities in the preceding week) in two dimensions: (1) amount of use (AOU), that is, how often the more-affected upper extremity was used; and (2) quality of movement (QOM), that is, how well the tasks were performed (Uswatte et al., 2006). However, self-reporting might influence the accuracy of the assessment; for example, cognitive functioning is often impaired following a stroke and this could affect a respondent's recall; further, a respondent's desire to satisfy an assessor, avoid embarrassment, and so on might lead to exaggerated self-rating of a respondent's performance/abilities (Adams et al., 2005; Prince et al., 2008).

Correlation between MAL and other upper extremity assessments may reflect the reliability of stroke patients' self-rating, but there has been little research into this issue. A trial conducted by van der Lee *et al*. found that a translated version of MAL showed moderate correlation with the Action Research Arm Test (ARAT; ρ=0.63); however, after a 2-week intervention, the improvement in the

MAL assessment was only weakly correlated with the improvement in the ARAT assessment (van der Lee et al., 2004).

Use of accelerometers is becoming common for the purpose of counting the number of movements made by an affected upper extremity of stroke patients or quantifying the ratio of the movement of an affected extremity to the movement of a non-affected or less-affected extremity (Noorkoiv et al., 2014). Most of these studies have found the ratio to have significant (moderate to high) correlations with assessment based on MAL in subacute or chronic stroke patients (Uswatte et al., 2006; van der Pas et al., 2011; Noorkoiv et al., 2014; Narai et al., 2016). Similar findings were revealed in the study conducted by van der Pas *et al*., who recruited chronic patients living in their home environment (r=0.60 and r=0.66) (van der Pas et al., 2011). Narai *et al*. found that the amount of movement of a unilaterally-affected upper extremity as recorded by an accelerometer showed moderately good correlation with the MAL's AOU and QOM subscales in acute or subacute stroke patients (r=0.58 and r=0.55, respectively) (Narai et al., 2016). In other studies, however, there were no significant changes in the amount of movement and the ratio of paretic upper extremity use to less-affected extremity use as recorded by the accelerometers (Rand and Eng, 2012; Fong et al., 2011; Fong et al., 2013).

Smart wearable devices with motion sensor data are currently popular and commercially available in the market for ongoing assessment of clients during community functioning and recommendations to therapists about how to progress exercise and skills practice. However, efficacy and effectiveness trials are necessary before clinicians can utilize sensor data for ecologically sound monitoring and outcome measures (Dobkin, 2013). It would be important to the literature in stroke rehabilitation if the use of unilateral accelerometer can be adopted to measuring the use of paretic upper extremities after stroke. Therefore, the purposes of this study were to explore the utility of the unilateral accelerometers worn by subacute stroke patients who had been

discharged from the hospital, as well as, to investigate the relationship between self-reported change in affected upper extremity use as measured by the MAL and the paretic upper extremity functional performance by other conventional instruments.

Methods

Participants

Twenty-four subacute stroke patients were recruited while about to be discharged from 2 local hospitals. The inclusion criteria were as follows: (1) the patient had suffered a first-time hemorrhagic or ischemic stroke; (2) less than 6 months had elapsed since the stroke; (3) the patient's muscle tone was ≤ 2 on the Modified Ashworth Scale (Bohannon and Smith, 1987); (4) the patient had not received a botulinum injection within the preceding 3 months; (5) the patient's score on the Functional Test for Hemiplegic Upper Extremity – Hong Kong Version (FTHUE-HK) was ≥ 3 (Fong et al., 2004); (6) no pain or swelling was affecting the upper extremity movement of the patient; (7) the patient was able to ambulate independently with or without walking aid; and (8) was able to understand verbal instructions and follow one-step commands using the Mini-mental State Examination (MMSE) ⩾ 19 (Chiu et al., 1994). All of the participants were required to sign a written consent form when they were recruited. Ethical approval was sought from the Human Subjects Ethics Committee of The Hong Kong Polytechnic University (HSEARS20110401010) and ethics committees of related hospitals (KC/KE-11-0099/ER-1 and NTWC/CREC/1048/12). The data of this study were obtained from a randomized clinical trial investigating the effects of 'Remind-to-move' by means of vibration cueing emitted through a wearable wristwatch device for promoting upper extremity recovery in patients with subacute stroke (Wei & Fong, 2016).

Equipment

The wristwatch device –Model SCW-V2, used in this study, was designed by the team and has been employed in previous studies (Fong et al., 2011; Fong et al., 2013) (Figure 1). It has a weight of 70 grams and is 6.5X6.0X2.5cm in size. The implanted tri-axial accelerometer in form of a 3D coordinate system built-in the device can sample data at a frequency range of 1Hz to 10 Hz, and the epoch time can be set from 1 second to 60 minutes. Figure 2 illustrates the unidirectional acceleration magnitude of the arm motion in terms of the axes X, Y, and Z of the device (mathematically $=|\vec{X}|,|\vec{Y}|,|\vec{Z}|$). The battery can keep the device running continuously for up to 72 hours, and all of the data was stored on a micro SD card. Arm swing during human walk is about 1 to 3 Hz while tremor frequency during intentional movements in wrist and elbow are between 3-7 Hz (Ketteringham et al., 2007), therefore, the sampling rate of the device in this study was set at 5 Hz which was able to detect voluntary movements and reduce too much noise in involuntary movements, such as tremor. The epoch time selected in this study was 2 seconds, as in a previous study (Uswatte et al., 2006); and the method of counting movements that was employed in a previous study (van der Pas et al., 2011) was adopted in this study.

Assessments

The standardized assessments employed were Fugl-Meyer Assessment Upper Extremity subscale (FMA-UE), ARAT, the Box and Block Test (BBT), and MAL. The Fugl-Meyer Assessment (FMA) is a popular instrument for assessing the impairment level in stroke patients with moderate to severe impairments; it covers five domains: motor performance (of upper and lower extremities), sensation, balance, range of motion, and pain. The upper extremity subscale used in this study (FMA-UE) contains 33 items, with a maximum score of 66 (Fugl-Meyer et al., 1975); the guidelines followed were those published in a previous study (Sullivan et al., 2011). ARAT is a popular instrument for assessing the paretic upper extremity functions after stroke; it has 19 items covering four domains: grasp, grip, pinch, and gross movement. The maximum score is 57 (Lyle,

1981). The guidelines followed were those published in a previous study (Yozbatiran et al., 2008). BBT evaluates dexterity performance by counting how many blocks are transferred from one box to another within 1 minute (Mathiowetz et al., 1985); it may be used with mildly- to moderately-impaired stroke patients. MAL is a questionnaire based on the theory of learned non-use; stroke patients are required to self-rate their functioning in two dimensions (amount of use and quality of use of an affected extremity) covered by 30 items concerning daily activities. The scores indicate the amount of use and quality of performance of an affected upper extremity in daily life; the maximum score is 150 for each dimension (Uswatte et al., 2006). The MAL used in this study had been previously translated and adapted to cultural context in Hong Kong, e.g. use of chopsticks was added instead of using a fork or spoon for eating (Ng et al., 2008).

Procedure

All of the stroke patients who participated in this study were assessed by all but one of the standardized assessments immediately before when they were discharged from the hospital - MAL could not be used at that time because MAL requires the respondents to have some experience performing the activities in the home and in the community after a stroke.

After being discharged from the hospital, the participants were required to wear the wristwatch device on the dorsal surface of the affected wrist during waking hours continuously for 3 hours/day during the daytime – before or after lunch, for 4 weeks and were told that the device would record the movement of their affected upper extremity. The participants were required to wear the device for 3 hours daily at home, as in our previous studies (Fong et al., 2011; Fong et al., 2013), to make sure the wearing time throughout the time did not coincide with outpatient rehabilitation times during which the participant would be very active. After 4 weeks, the device was returned to the

investigators for data analysis; and the participants were assessed by the standardized assessments at 4-, 8-, and 12-weeks. All of the assessments were conducted by the same assessor.

Statistical analysis

How long the accelerometer was worn, the amount of movement, the amount of movement per hour, and the movement percentage were extracted from the data recorded by the accelerometer. The range of accelerometry was set at ±1.5G for the amount of movement counting. Movements were counted based on the number of peaks created by the accelerometry curve which was drawn by the integrated value of x, y, and z axes ($\sqrt{|x|^2+|y|^2+|z|^2}$). Each participant was required to wear the device for 3 hours a day; when this 3-hour period was broken into several intervals (T_1, T_2, T_x) the overall movement percentage ($P_{overall}$) for that day was weighted by the periods during which the device was worn: $P_{overall} = (P_1\ T_1+P_2\ T_2+P_x\ T_x) / (T_1+T_2+T_x)$. The Friedman test and Spearman's rank correlation coefficients were used to analyze the within-group differences and relationships between the assessments. The correlation levels were set as follows: weak or no correlation (0 to 0.25); fair correlation (0.25 to 0.5); moderate correlation (0.5 to 0.75); and excellent correlation (above 0.75); (Portney and Watkins, 2009). A *p* value of less than 0.05 was taken to indicate a significant difference/correlation.

Results

The characteristics of the participants are shown in Table 1. Most of the participants were male (79%), had suffered an ischemic stroke (83%), were left side affected (67%), and had been educated to secondary (50%) or primary (38%) levels. All participants were right dominant.

The Friedman test revealed that the FMA-UE, ARAT, and BBT assessments of upper extremity performance showed significant within-group differences ($p<0.001$, $p=0.026$, and $p<0.001$, respectively), and largest gain was between the baseline and 4-week assessment; the MAL

assessments showed improvement, but no significant change was evident (AOU, p=0.189; QOM, p=0.068). The data extracted from the accelerometers indicated no significant changes throughout the whole 4-week observation period (p=0.368 to p=0.999; see Table 2).

The Spearman's rank correlation coefficients indicated that all the assessments presented moderate to excellent correlations, and the correlation indexes remained stable across the 12 weeks (see Table 3); no significant correlation could be observed between the functional gains shown in the assessments except that there were moderate correlations between AOU and QOM (ρ=0.64) in the 4- and 8-week assessments and (ρ=0.70) in the 4- and 12-week assessments and ARAT showed a fair degree of correlation with BBT in the 4- and 12-week assessments (ρ=0.41). There was no significant correlation between the data extracted from the accelerometers and the conventional assessment measures, and between the MAL with other performance measures.

With regard to the accelerometer data only, the amount of time the device was worn correlated fairly well with the amount of movement (ρ=0.48) but was not significantly correlated with the amount of movement per hour or movement percentage; however, the correlations among amount of movement, amount of movement per hour, and movement percentage were excellent (p=0.78 to p=0.91; see Table 4).

Discussion

This study investigated the correlations among assessments of upper extremity functioning, measured by the use of the MAL and by other instruments – in subacute stroke patients discharged immediately from hospitals; it also explored the use of a unilateral accelerometer worn on a paretic wrist to assess the use of an affected upper extremity in a home environment.

Motor function improvement among stroke patients in the subacute stage might result from spontaneous recovery and appropriate rehabilitation interventions (Buma et al., 2013). Most of the

participants in this study were receiving regular out-patient rehabilitation training, and significant improvements during the 12-week observation period were reflected in all of the conventional assessment instruments. The largest improvements occurred between 0- and 4-weeks; however, no significant change was revealed by the accelerometer parameters (amount of movement, amount of movement per hour, and movement percentage). Similar findings were reported in our previous studies of chronic stroke patients and in-patient subacute stroke patients with unilateral neglect (Fong et al., 2011; Fong et al., 2013). Rand and Eng (Rand & Eng, 2012) investigated upper extremity functioning among in-patient subacute stroke patients and found no significant change in the amount of movement of paretic and non-paretic extremities over a 3-week period; other assessments have found that upper extremity functioning improves significantly during this period. These findings suggest that the number of movements recorded by an accelerometer does not indicate the quality of the movements; and it may not accurately indicate the frequency of use of an upper extremity if the accelerometer is worn for only 3 hours a day. We can conclude that for detecting functional improvement, accelerometers might not be as sensitive as conventional assessments. This finding has implications since commercial, wearable accelerometer devices or smartwatches are easily purchased, the use of these devices to record the paretic limb movements on stroke patients should be used with cautions, as either the data might not be reliable, or they might not accurately reflect the quality and quantity of movement.

Stroke patients with more severe impairments to the functioning of an upper extremity tend not to employ their affected side and exhibit more severe learned non-use (Taub et al., 2006). Van der Lee *et al*. found that MAL measurements of learned non-use in chronic stroke patients had a moderately strong correlation with those of ARAT, however, the scores gained in these two assessments were weakly correlated or not correlated at all (van der Lee et al., 2004). This phenomenon was consistent with the findings of our current study on subacute stroke patients that were stable

moderately strong correlations across the three assessment points. Furthermore, FMA-UE (which was used for moderately to severely impaired patients) and BBT (which was employed for slightly to moderately impaired patients) showed moderately strong to very strong levels of correlation with MAL. This might indicate that the self-report MAL questionnaire accurately reflects the respondents' paretic arm functioning if stroke patients are able to recall from their recent experiences (Woodfield and Sudlow, 2015). The presence of cognitive impairment might not be an important factor in recalling experiences, as the participants in this study had relatively good cognitive performance (Table 1).

Some studies have found that the movement ratio estimated by comparing both upper extremities using data from an accelerometer is moderately well correlated with MAL assessments (Uswatte et al., 2006; van der Pas et al., 2011; Noorkoiv et al., 2014). Van der Pas *et al*. even revealed that the data extracted from a unilateral accelerometer showed moderately strong correlation with MAL assessments; however, further analysis revealed that this correlation held only with the participating stroke patients in whom the dominant side was affected – there was no significant correlation with regard to the participating stroke patients in whom the non-dominant side was affected (van der Pas et al., 2011). As seen in our results, the preferred side of all our participants was the right side; but 16 out of the 24 (67%) were affected on the left upper extremity, i.e. the non-dominant side. The movements counted by a unilateral accelerometer could be impacted by whichever is the preferred side and how many activities involve self-care, work/study, and leisure, especially if these activities require more unilateral involvement – for example, using chopsticks/a spoon, writing with a pen or pencil, or using a mouse to surf the internet. In future, the use of dual-accelerometers might have greater potential for accurately evaluating learned non-use in a home environment because of individual variations in daily activities engagement (Bailey, Klaesner, & Lang, 2014).

Limitations

This study has several limitations: (1) we used a unilateral accelerometer to investigate upper extremity use, but the approach for counting the amount of movement and movement percentage could not eliminate the influence of ambulatory arm swing; (2) movement quality is an important element in motor learning, but the accelerometer currently available cannot distinguish the movement patterns made by a user; (3) participants were discharged immediately from hospitals and were required to attend regular outpatient rehabilitation 2-3 times per week at clinics, so wearing the device for 3 hours per day might not be sufficient to reflect the arm performance throughout the day, and the study did not specific the time of day to wear the device; and (4) although this study was carried out on subacute stroke, the generalizability of the findings was limited by the small sample size.

Conclusion

The stable moderate-to-excellent correlations with motor performance indicates that the MAL is useful in subacute stroke patients, however, using unilateral accelerometer data to assess real-life upper extremity use in people with motor impairments is of questionable value, even our tailor-made device could not yield data that accurately reflected the functional change as measured by the assessments of upper extremity functioning.

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Declaration of interests

The authors have no disclosure of any commercial interest relevant to the subject of this manuscript except disclosure of patents of SCW-V2 (US patent: US-2010-0160834-A1 and Chinese patent: 200910175541.7).

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Table 1 Demographic characteristics of the participants (n=24)

Variable	Mean (SD) or Number (%)
Gender	
Male	19 (79%)
Female	5 (21%)
Type of stroke	
Hemorrhagic	4 (17%)
Ischemic	20 (83%)
Age (years)	60.65±10.71
Time since onset (days)	64.33±41.59
MMSE	26.87±3.20
Education level	
No formal education	2 (8%)
Primary	9 (38%)
Secondary	12 (50%)
College	1 (4%)
Affected side	
Left	16 (67%)
Right	8 (33%)

Data are n (%) or mean (SD); MMSE, Mini Mental Status Examination.

Table 2 Upper extremity performance at different time occasions (n=24)

	0-week assessment	4-week assessment	8-week assessment	12-week assessment	*p*
FMA-UE	50.63±16.81	54.13±15.68	55.79±15.79	56.17±15.75	0.000
ARAT	35.25±21.87	38.21±22.76	40.13±22.72	40.58±22.99	0.026
BBT	20.96±17.06	27.63±18.74	31.69±20.80	35.13±22.67	0.000
MAL					
AOU	NA	2.26±1.46	2.43±1.49	2.88±1.46	0.189
QOM	NA	2.40±1.26	2.60±1.30	2.98±1.24	0.068
Accelerometer	(1^{st} week)	(2^{nd} week)	(3^{rd} week)	(4^{th} week)	
Average time worn per day (hours)	3.64±2.16	3.83±2.53	3.64±1.60	3.32±1.43	0.999
Average amount of movement	762.71±559.55	695.93±444.89	750.74±481.42	673.58±440.61	0.912
Average amount of movement per hour	210.77±118.76	196.50±101.20	214.69±99.02	214.85±104.61	0.368
Averaged movement percentage	9.49±5.56	9.00±4.31	9.73±4.26	9.41±5.02	0.701

AOU, Amount of Use; ARAT, Action Research Arm Test; BBT, Box and Block Test; FMA-UE, Fugl-Myer Assessment–Upper Extremity Subscale; QOM, Quality of Movement; MAL, Motor Activity Log.

Table 3 Correlations between the assessments (n=24)

	FMA-UE (4w/8w/12w)	ARAT(4w/8w/12w)	BBT(4w/8w/12w)	MAL-AOU(4w/8w/12w)
ARAT	0.86/0.87/0.84			
BBT	0.82/0.70/0.73	0.83/0.79/0.85		
MAL-AOU	0.61/0.69/0.76	0.64/0.59/0.66	0.58/0.50/0.52	
MAL-QOM	0.66/0.70/0.88	0.60/0.67/0.78	0.59/0.68/0.67	0.94/0.88/0.81

AOU, Amount of Use; ARAT, Action Research Arm Test; BBT, Box and Block Test; FMA-UE, Fugl-Myer Assessment–Upper Extremity Subscale; QOM, Quality of Movement; MAL, Motor Activity Log.

Table 4 Correlations between the parameters measured by the accelerometer (n=24)

	Amount of time the device was worn	Amount of movement	Average amount of movement per hour
Amount of movement	0.48		
Average amount of movement per hour	NS	0.80	
Movement percentage	NS	0.78	0.91

NS, non-significant correlation.