Author/s:
Chin, LF;Hayward, KS;Soh, AJA;Tan, CM;Wong, CJR;Loh, JW;Loke, GJH;Brauer, S

Title:
An accelerometry and observational study to quantify upper limb use after stroke during inpatient rehabilitation

Date:
2019-10-01

Citation:
Chin, L. F., Hayward, K. S., Soh, A. J. A., Tan, C. M., Wong, C. J. R., Loh, J. W., Loke, G. J. H. & Brauer, S. (2019). An accelerometry and observational study to quantify upper limb use after stroke during inpatient rehabilitation. Physiotherapy Research International, 24 (4), https://doi.org/10.1002/pri.1784.

Persistent Link:
https://hdl.handle.net/11343/285872

Chin Lay Fong (Orcid ID: 0000-0002-5795-7554)

Title Page

Informative Title:

An Accelerometry and Observational Study to Quantify Upper Limb Use after Stroke during Inpatient Rehabilitation

Running Title:

To Understand Stroke Inpatient Upper Limb Use

This is the author manuscript accepted for publication and has undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1002/pri.1784

Main Author:

Name: Lay Fong Chin

Affiliations:

[1]Tan Tock Seng Hospital Rehabilitation Centre, Singapore 569 766

[2]Physiotherapy, School of Health and Rehabilitation Sciences, University of Queensland, Brisbane Australia 4072

[3]NMRC Singapore, Ministry of Health Singapore, Singapore 099 253

Co- Authors:

Name: Kathryn S Hayward

Affiliations:

[1] Physiotherapy, School of Health and Rehabilitation Sciences, University of Queensland, Brisbane Australia 4072

[2] AVERT Lab, Stroke Theme, Florey Institute of Neuroscience and Mental Health, University of Melbourne, Melbourne VIC Australia 3084

[3] NHMRC Centre of Research Excellence in Stroke Rehabilitation and Brain Recovery, Australia

Name: Aloysius Jun An Soh

Affiliations:

[1] Singapore Institute of Technology- Nanyang Polytechnics, Singapore 567 739

[2] Khoo Teck Puat Hospital, Singapore 768 828

Name: Chin Mei Tan

Affiliations:

[1] Singapore Institute of Technology- Nanyang Polytechnics, Singapore 567 739

Name: Cheryl Jing Ru Wong

Affiliations:

[1] Singapore Institute of Technology- Nanyang Polytechnics, Singapore 567 739

Name: Jia Wei Loh

Affiliations:

[1] Singapore Institute of Technology- Nanyang Polytechnics, Singapore 567 739

Name: Genevieve Jia Hui Loke

Affiliations:

[1] Singapore Institute of Technology- Nanyang Polytechnics, Singapore 567 739

Name: Sandra Brauer

Affiliations:

[1] Physiotherapy, School of Health and Rehabilitation Sciences, University of Queensland, Brisbane Australia 4072

Corresponding Author:

Name: Lay Fong Chin

Mailing address:

Tan Tock Seng Hospital Rehabilitation Centre, 17 Ang Mo Kio Ave 9, Singapore 569 766

Telephone no: +65 6507 0621

Email: Lay_Fong_CHIN@ttsh.com.sg

Acknowledgements

We thank Dion Scott for his valuable assistance in the development of the processing scripts for accelerometry data in Matlab. We thank Keng He Kong for his esteemed advice and Bernadine Teng and Audrey Chai for their support in data collection.

LFC is supported by National Medical Research Council Singapore (MH 95:03/8-1031).

KH was supported by a National Health and Medical Research Council Early Career Fellowship (1088449). The Florey Institute of Neuroscience and Mental Health acknowledge the strong support from the Victorian Government and in particular the funding from the Operational Infrastructure Support Grant.

Disclosure statement

No potential conflict of interest was reported by the authors

Abstract:

Objectives:

To characterize paretic upper limb (UL) use in people with different levels of impairment 4-weeks post-stroke; and compare accelerometry and direct observational approaches.

Methods:

Twelve stroke inpatients (5 mild, 3 moderate, 4 severe UL impairment) were recruited from a rehabilitation hospital. UL use was measured using accelerometry (24-hours) and direct observation (12-hours of behavioural mapping). Accelerometry variables included duration of use, use ratio, magnitude ratio, bilateral magnitude and variation ratio. Direct observation recorded the duration of use and type of UL movement (e.g. functional versus non-functional).

Results:

From accelerometry data, people with mild, moderate, and severe UL impairments used their paretic UL 59%, 45%, and 22% of a 24hr-day respectively. People with severe UL impairment had the lowest paretic UL use duration (median 1.49 hours/day), magnitude ratio and variation ratio compared to people with mild and moderate UL impairment. From 12-hours of observational data, people with mild impairment were using their UL for 37.8% of the observed time, while the people with moderate and severe impairment were using their UL 15.8% and 4.9% respectively. UL movements for the mild cohort were mainly functional, while UL movements of the moderate and severe cohorts were mainly non-functional. UL movements were predominantly active for the mild and moderate cohorts, but passive for the severe cohort. Duration of paretic UL use from accelerometry and observation data were highly correlated (ICC > 0.8), but the absolute percentage error between methods ranged from 34.2% to 42.7%.

Conclusions:

Paretic UL use within the first 4-weeks post-stroke differs across levels of impairment in this exploratory study. Accelerometry and observation findings of paretic UL use were correlated, and may be needed in different situations as they capture different information.

Keywords: accelerometry; observation; stroke; upper limb; use

Introduction

Few people with stroke achieve complete upper limb (UL) recovery (Kwakkel, Kollen, van der Grond & Prevo, 2003; Kong & Lee, 2013). Initiation of rehabilitation within the first 4-weeks post-stroke is crucial as it is the period of most rapid UL recovery after stroke (Duncan, Goldstein, Horner, Landsman, Samsa & Matchar, 1994), with approximately 80% of people achieving their maximal UL function during this window of time (Nakayama, Jorgensen, Raaschou & Olsen, 1994). This window is also defined as the period when the neuroplastic potential of the brain is heightened (Krauker, Carmichael, Corbett & Wittenberg, 2012; Kreisel, Bazner & Hennerici, 2006). Through greater use and practice of the paretic UL, people with stroke can achieve greater recovery (Han, Wang, Meng & Qi, 2013). Yet, not using the paretic UL can be detrimental to recovery and lead to compensatory strategies (i.e. greater use of non-paretic UL), which hinder neuroplastic processes of recovery (Kleim & Jones, 2008). Therefore, promoting use of the paretic UL early post-stroke is crucial.

In order to design interventions that target increased use of the paretic UL post-stroke, there is a need to understand use early in rehabilitation during and outside therapy. Accelerometry has been found to be a valid and reliable tool to measure UL use in people with stroke (Uswatte, Giuliani, Winstein, Zeringue, Hobbs & Wolf, 2006), and distinguish between paretic and non-paretic limbs (Bailey, Klaesner & Lang, 2014; Bailey, Klaesner & Lang, 2015). However, a limitation of accelerometry is an inability to provide information about the quality and type of UL movements and activities performed (Hayward, Eng, Boyd, Lakhani, Bernhardt & Lang, 2016; Rand & Eng, 2010). Direct observational studies enable the type of UL movement and activities to be recorded (Lang, MacDonald & Gnip, 2007; Connell, McMahon, Simpson, Watkins & Eng, 2014; Lang et al., 2009). However, observation is labour-intensive, and thus, has far been largely used to examine the use of paretic UL during therapy sessions only (Lang, MacDonald & Gnip, 2007; Connell, McMahon, Simpson, Watkins & Eng, 2014; Lang et al., 2009). Only one observational study has observed UL use after stroke during and outside therapy in the hospital (Bernhardt, Chan, Nicola & Collier, 2007). This study reported the proportion of paretic UL use during nine hours of observation was 6% during therapy and 1% outside therapy, but did not provide detailed information about the quality or type of UL movements and activities (Bernhardt, Chan, Nicola & Collier, 2007). There remains a lack of information on the type of paretic UL movements and use pattern across different UL severity levels early post-stroke. This information is important as it can help clinicians to develop strategies to increase UL use for individuals with different levels of function during early rehabilitation.

Most studies investigating paretic UL use during early rehabilitation have been completed using accelerometry or direct observation alone (Bernhardt, Chan, Nicola & Collier, 2007; Lang, Wagner, Edwards & Dromerick, 2007; Rand & Eng, 2012; Urbin, Waddell & Lang, 2015). Only two studies have been completed using both accelerometry and direct observation to study paretic UL movement after stroke. These two studies have only investigated people with stroke in the chronic phase during treatment sessions and found a moderate-high correlation between the number of repetitions observed during purposeful exercises and recorded via accelerometry during therapy (Connell, McMahon, Simpson, Watkins & Eng, 2014; Rand, Givon, Weingarden, Nota & Zeilig, 2014). Thus far, no studies have compared the accuracy of accelerometry to measure paretic UL use with direct observation during the early sub-acute phase post-stroke. A comparison between these two approaches is important to validate the use of accelerometry for people during early rehabilitation.

Therefore, this exploratory study aims to use both the accelerometry and direct observation methods to fill these knowledge gaps. The aims of this study are:

1. To characterize and compare paretic UL use in people in rehabilitation up to 4-weeks post-stroke across different UL severity levels.
2. To compare UL use captured using accelerometry and direct observation for people with stroke during early subacute rehabilitation.

Methods

Study Site

Participants were recruited from Tan Tock Seng Rehabilitation Centre in Singapore, a subacute rehabilitation hospital with 50 beds dedicated to stroke patients. This study was approved by the research ethics committee of the National Healthcare Group Domain Specific Review Board in Singapore and the University of Queensland, Australia and confirms with the Declaration of Helsinki.

Participants

People were included if they had a diagnosis of first ever stroke (confirmed on MRI/CT) ≤4 weeks prior to enrolment and were medically stable. People were excluded if they experienced a bilateral stroke; exertional dyspnea, angina or severe fatigue; existing neural or orthopedic conditions that limited UL use prior to stroke; were unable to give consent; or had neglect, agitation, delirium/dementia, or depression that could result in poor accelerometer wear compliance.

We purposely recruited people with different levels of UL motor capability defined by the UL section of the Fugl Meyer assessment (FMUL, /66 points). Stratification was based on cut-off scores previously defined (Woodbury, Velozo, Richards & Duncan, 2013): 51-66 (mild), 23-50 (moderate), 0-22 (severe).

Procedure

A tri-axial accelerometer (ActiGraph GT3X+, ActiGraph LLC, Pensacola, Florida) was placed on each wrist for a 24-hour period on a weekday, and was only removed when showering. Monitoring UL activity with accelerometers for 24 hours is a practical compromise between sufficient time of monitoring to reflect a typical day on the ward (Bernhardt, Chitravas, Meslo, Thrift & Indredavik, 2008) and optimization of participant compliance (Bailey & Lang, 2012).

Direct observation of paretic UL use was performed from 8 am to 8 pm within the 24-hour period of donning accelerometers. Participants were informed that their activities on the ward and in therapy would be observed. They were not observed during any medical procedures when the curtains were drawn around the bed, in the toilet or shower cubicles. During direct visual observation, paretic UL movements were observed continuously and recorded in seconds using a stopwatch, the same frequency of recording used by the accelerometers (one second per epoch). The start and stop times of physiotherapy and occupational therapy sessions were recorded during the observation to calculate the duration of each therapy session and to aid extraction of accelerometry data captured during and outside therapy.

An UL movement was defined as "any movement made at any segment(s) of the hemiparetic upper extremity" (Lang, MacDonald & Gnip, 2007), and were categorized as functional or non-functional, and passive or active. Functional UL movements (purposeful movement) were defined as "any movement that accomplished or attempted to accomplish a specific and functional goal, or any movement that simulated a specific functional task" e.g. reaching for a cone (Lang, MacDonald & Gnip, 2007). Non-functional UL movements were defined as any UL movement that was performed without accomplishing a specific and functional goal. Categories of functional and non-functional movements used in this study are listed in supporting information. Passive movements were defined as any movement at the patient's joint(s) made by the therapist or another outside source, without detectable effort by the patient. (Lang, MacDonald &

Gnip, 2007). In this study, passive movements were also defined as any movements performed by the patient's non-paretic UL without any effort exerted by the paretic UL. In contrast, active movements were defined as any UL movements made with effort exerted by the paretic UL. Based on the functional categories, UL movement was coded as passive or active movement.

The principal investigator and five physiotherapy students completed direct observation. The students were trained by the principal investigator in categorizing UL movements by watching video recordings of stroke patients' UL movements performed in hospital. The five students then underwent two video tests of categorizing UL movements and achieved 95% agreement before commencing direct observation. Two main observer arrangements were made. For 7 participants, the same person observed for the entire 12 hours. For these participants, an extra observer was on standby to substitute when the observer needed to go for lunch and toilet breaks. For the other 5 participants, two observers took shifts to cover the 12 hours of observation for each participant. Observers were instructed to observe the UL movements.

Outcome Measures

Participant Characteristics. Demographic data included age, sex, diagnosis (stroke due to infarct or haemorrhage), paretic side, days since stroke, days since admission to rehabilitation centre, stroke severity (National Institute of Health Stroke Scale (NIHSS) (Rangaraju, Frankel & Jovin, 2016), and Montreal Cognitive Assessment (MoCA)

(Chiti & Pantoni, 2014) on admission to rehabilitation centre. The Functional Independence Measure (FIM) (Beninato et al., 2006; Kidd et al., 1995) was performed within 5 days of donning of the accelerometers. Upper limb dominance, FMUL (Gladstone, Danells & Black, 2002), Nottingham Sensory Assessment (NSA-revised version) (Lincoln, Jackson & Adams, 1998), and grip and lateral pinch force of the paretic UL were assessed within 5 days of accelerometer donning.

Accelerometry. Acceleration from the ActiGraph GT3X+ accelerometers was sampled at 60Hz. Data were integrated into 1 second epochs using ActiLife 6 software (ActiGraph; Pensacola, FL) and the summed acceleration across the three axes (vector magnitude) calculated. All data were smoothed using a 5-sample moving average to reduce the variability of vector magnitude (Bailey, Klaesner & Lang, 2014). The presence of UL movement was defined as a vector magnitude of ≥2 activity counts for at least one second (Uswatte, Wolfgang, Foo, Varma, Moran & Taub, 2000). Accelerometry-derived metrics were calculated using the approach described by Bailey, Klaesner & Lang, 2015 and Urbin, Waddell & Lang, 2015. This includes the metrics of duration of paretic and non-paretic UL use during the complete 24-hours of donning accelerometers; ratio of duration of paretic/non-paretic UL use (use ratio); ratio of magnitude of paretic/non-paretic UL use (magnitude ratio); sum of vector magnitude of bilateral UL use (bilateral magnitude); and ratio of variability (standard deviation) of paretic/non-paretic UL use (variation ratio). Magnitude ratio was calculated for each second of UL use by first dividing the vector magnitude of the paretic UL with the non-paretic. The calculated values were then natural logarithm transformed. UL use data that could not be transformed (due to zero in the numerator or denominator) were allocated -7 for non-paretic and +7 for paretic unilateral use. Negative values indicated greater use of the non-paretic UL than paretic UL, positive values indicated greater use of the paretic UL, and 0 represented relatively equal use of paretic and non-paretic ULs. Bilateral magnitude was calculated by summing the vector magnitude of the paretic UL and non-paretic UL for each second of UL use. All variables were calculated using custom scripts created in Matlab R2015a (Mathsworks, Nattick, IL) software.

Observation Outcome Measures. The duration (seconds) of active, passive, functional and non-functional movements and their subcategories were summed across the 12-hour observation period for each individual participant.

Statistical Analysis

Descriptive statistics were used to describe participant demographics and characterize the activity of the paretic UL for the three impairment groups (mild, moderate and severe UL paresis). Histograms of magnitude ratio and bilateral magnitude within individuals were used to check for normality. The median of each individual variable of interest was used for comparison. To compare the accuracy of accelerometry and observational findings, Intraclass Correlation Coefficient ($ICC_{3,1}$) with a 95% confidence interval (CI) and Absolute Percentage Error (APE) which measured percentage accuracy (Brandimarte & Zotteri, 2007) were calculated. In our study, the

APE measured the percentage accuracy in the duration of paretic UL use between the accelerometry data and observation. APE was calculated for the whole cohort using the following formula:

APE = [Mean (absolute difference between 12 hours of accelerometry data and observation)/ Mean (average of 12 hours of accelerometry data and observation)] x 100. Bland-Altman plots were used to quantify the mean differences and the upper and lower limits of agreement (mean difference +/- (1.96x SD)) visually. Statistical analysis was performed using SPSS software (version 16.0) and significance was set at $p<0.05$.

Results

Participant Characteristics

Twelve stroke inpatients (five participants with mild, three with moderate, and four with severe UL impairments) ≤4-weeks post-stroke were recruited (Table 1). This number was chosen to feasibly complete the labour-intensive 12-hour observation with accelerometry. The participants with moderate UL impairment appeared to be younger than the other two groups. Participants with severe UL impairment were also the most severe in terms of overall stroke severity (NIHSS); FIM measures of self-care ability, transfer ability, and mobility; and cognitive impairment (MOCA) compared with participants with moderate and mild UL impairment. Physiotherapy session duration was greatest in participants with severe UL impairment, whilst occupational therapy session duration was longest in participants with moderate UL impairment. Three participants with mild impairment did not require occupational therapy.

Insert Table 1 near here

Accelerometry Findings

Table 2 shows the 24-hour accelerometry data collected for 11 participants. Data from one participant with moderate impairment was removed due to extreme difference between accelerometry and observational data (mean difference of 4.2 hours during 12 hours of observation). Participants with severe UL impairment used their paretic UL least and had the lowest use ratio (severe=0.22, moderate=0.45, mild=0.59), bilateral magnitude (severe=54.5, moderate=58.7, mild=83.4) and variation ratio (severe=0.35, moderate=0.57, mild=0.62) when compared with participants with moderate and mild UL impairments across 24 hours. The therapy sessions (physiotherapy and occupational therapy) accounted for 20.6% of paretic UL use across 24 hours in those with mild impairment, 24.6% of the time for those with moderate and 36.9% of the paretic UL use time in those with severe impairment. Use ratio and median magnitude ratio were consistently higher during therapy sessions compared with outside therapy sessions across all groups (Table 2).

Insert Table 2 near here

Observational Findings

Figure 1 demonstrates the paretic UL movement in participants across the three severity levels. Generally, as severity of impairment reduced, the proportion of active and functional movements increased.

Insert Figure 1 near here

When type of activities was evaluated (Table 3), those with mild UL impairment used their paretic UL most in functional activities and basic ADLs, while activity in moderate impairment was spread across active-assisted exercises, functional activities, passive stretching, passive positioning and active strengthening exercises. Participants with severe UL impairments were limited to mainly passive stretching, passive positioning, and very limited functional activities.

Insert Table 3 near here

Comparison of Accelerometry and Direct Observation

Accelerometry and direct observation measurement of the duration of UL use were significantly positively correlated ($p<0.001$) across the 12-hours of direct observation (ICC = 0.882, 95%CI 0.64-0.97), during occupational therapy (ICC = 0.890, 95%CI 0.66-0.97), physiotherapy sessions (ICC = 0.853, 95%CI 0.54-0.96), and outside therapy (ICC = 0.886, 95%CI 0.64-0.97). There was a moderate absolute percentage error between accelerometry and observation findings across the 12-hours of direct observation (34.2%), during occupational therapy (37.5%) and physiotherapy sessions (42.7%), and outside therapy (39.7%). Higher levels of paretic UL use were recorded via accelerometry than direct observation for the majority of participants performing ≤ 300 minutes of UL activity. For those who completed >300 minutes of UL use, accelerometry recorded less paretic UL use than observed in two participants with mild UL impairment (Figure 2a and 2b).

Insert Figure 2 near here

Discussion

This study characterizes the use of the paretic UL in rehabilitation in people up to 4-weeks post-stroke with different levels of UL severity. It quantifies objectively how little people with severe UL impairment use their paretic UL in hospital, with predominantly non-functional movements performed at a low magnitude and variation. Positively, as severity of impairment reduced, participants demonstrated a greater proportion of active and functional movements performed throughout the day. This supports a recent study that showed those with more UL motor capability performed more active and purposeful repetitions of movement (Rand, Givon, Weingarden, Nota & Zeilig, 2014).

Current findings showed that participants with moderate impairment used their paretic UL less than those with mild impairment, concurring with a study of real-life UL use in chronic stroke (Shim, Kim & Jung, 2014). The use ratio found in our study falls within the range defined by others who have shown paretic UL use to be 20-75% of the non-paretic when in hospital, depending on severity level (Gebruers, Truijen, Engelborghs & De Deyn, 2013; Lang, Wagner, Edwards & Dromerick, 2007; Narai, Hagino, Komatsu & Togo, 2016; Rand & Eng, 2012).

The contribution of paretic UL use during therapy to overall paretic UL use per day in the current study appeared to be higher than that previously reported (Rand & Eng, 2012). A possible explanation is that participants in Rand and Eng (2012) had less severe UL impairment compared to this study, therefore they may have been able to use their paretic UL more independently outside therapy compared with participants of the current study. In support, in the current study, the severe UL impairment group had the highest proportion of paretic UL use during therapy compared to less impaired stroke survivors. Thus, despite the emphasis of paretic UL practice during therapy, minimal carry-over to outside therapy was seen for the severe group. This highlights a gap in the structure of therapy sessions. This would suggest that therapists need to teach and support stroke survivors (especially those with more severe UL impairment), caregivers, and nursing staff to engage in paretic UL activities outside therapy (Eng, Brauer, Kuys, Lord & Hayward, 2014).

The moderately strong correlation between accelerometry and observational findings agrees with two previous studies (Connell, McMahon, Simpson, Watkins & Eng, 2014;

Rand, Givon, Weingarden, Nota & Zeilig, 2014). Despite our moderate correlation, accelerometers recorded higher activity for use ≤300 minutes, and under-recorded use when it was >300 minutes. A possible explanation for the over-recording might be due to the accelerometer detecting small or whole body movements which were not observed and recorded as intentional UL movements by direct-observers. Raising the threshold for movement count considered consistent with motion on the accelerometer could address this in the future. We used the same threshold criteria for movement count as past work (Uswatte, Wolfgang, Foo, Varma, Moran & Taub, 2000). Higher levels of activity during observation were measured in two participants who spent long periods of time using the paretic limb in a support role (e.g. holding a phone), which was coded as a functional task, but as it was static, the accelerometers did not detect much movement. This highlights the limitation of accelerometers to detect "support" or static UL use or movements distal to the wrist. Similarly, identifying when the paretic UL may be used as an assisting hand in performing functional activities and bimanual tasks would provide a more complete picture of UL use particularly in those with moderate-severe paresis, but would require specific coding in observation. Nevertheless, the moderately strong correlation between accelerometry and observation findings reported in our study indicates that although not all use captured by the accelerometers reveal intentional UL movements (Lang, Wagner, Edwards & Dromerick, 2007), accelerometry can be used to compare UL use in people with stroke with different UL impairments without the manpower costs of observation.

The main limitation of this study is the small sample size which was recruited from one rehabilitation center. Being a major rehabilitation center in Singapore, the center admits approximately 32% of the 1800 stroke admissions in Singapore public hospitals annually (Singapore Ministry of Health, 2017). As direct observation of twelve hours of UL movements of people with stroke in the hospital was labour-intensive, only twelve participants were observed in this study. Observation can be modified to be less labour-intensive by reporting on a smaller component of time (e.g. recording 1 minute every 10), which would enable the one observer to move between patients in the same time period. This would enable representative (but not complete) data from more participants to be captured in the same time. Video recording participants could be used for capturing arm movement in a confined location, but ethical issues of privacy may limit wider data capture. Future research with larger sample size and across different rehabilitation centers is suggested to confirm generalizability of findings, and would permit subgrouping to examine differences between types of tasks. Another limitation is that even though the observers were trained and established consistency in coding movement, using only one rater could enhance consistency. We also cannot rule out the possibility that due to being observed, participants may have modified their behavior and increased their paretic UL use. Nevertheless, even if there was overestimation of actual use in the real world, we still found a low level of paretic UL use across different level of UL use.

Conclusions

This study has shown that after stroke, paretic UL use differs across varied levels of UL severity and supports the analysis of UL use by severity levels. Given the varied pattern of use throughout the day based on severity of paresis in this exploratory study, future studies need to measure UL use both inside and outside therapy. Measuring UL use is important to determine current level of function, which could in turn, assist clinicians to be more targeted in their treatment planning and education, as well as guide selection of strategies to promote out of therapy use to facilitate UL recovery. Due to the extremely low level and passive nature of paretic UL use in people with severe impairment, clinicians should pay particular attention to how to increase paretic UL use in this group, especially outside therapy. The moderately strong correlation between accelerometry and direct observation suggests that accelerometers may be used to capture UL use after stroke for longer time periods, but care needs to be taken in interpretation. Further investigation is required to confirm the preliminary findings of this exploratory study.

References

Bailey, R. R., Birkenmeier, R. L., Lang, C. E. (2015). Real-world paretic upper limb activity in chronic stroke: an examination of potential modifying factors. *Topics of Stroke Rehabilitation*, 22, 26-33.

Bailey, R. R. & Lang, C. E. (2013). Upper extremity activity in adults: referent values using accelerometry. *Journal of Rehabilitation Research and Development.*,50, 1213-22.

Bailey, R. R., Klaesner, J. W. & Lang, C.E. (2014). An accelerometry-based methodology for assessment of real-world bilateral upper extremity activity. PLoS One, 9(7)e103135. doi:10.1371

Bailey, R. R., Klaesner, J. W., Lang, C. E. (2015). Quantifying real-world upper-limb activity in nondisabled adults and adults with chronic stroke. *Neurorehabilitation and Neural Repair*, 29, 969-978.

Beninato, M., Gill-Body, K. M., Salles, S., Stark, P. C., Black-Schaffer, R. M. & Stein, J. (2006) Determination of the minimal clinically important Difference in the FIM instrument in patients with stroke. *Archives of Physical Medicine and Rehabilitation*, 87, 32-39.

Bernhardt, J., Chitravas, N., Meslo, I. L., Thrift, A. G., Indredavik, B. (2008). Not all stroke units are the same. A comparison of physical activity patterns in Melbourne, Australia and Trondheim, Norway. *Stroke*, 39, 2059-2065.

Bernhardt, J., Chan, J., Nicola, I. & Collier, J.M. (2007). Little therapy, little physical activity; rehabilitation within the first 14 days of organized stroke unit care. *Journal of Rehabilitation Medicine*, 39, 43-48.

Brandimarte, P. & Zotteri, G. (2007). Chapter 3- Forecasting (page 107): Introduction to distribution logistics. John Wiley & Sons Inc. New Jersey, USA.

Chiti, G. & Pantoni L. (2014). Use of Montreal Cognitive Assessment in patients with stroke. *Stroke*, 45, 3135 -3140.

Connell, L. A., McMahon, N. E., Simpson, L. A., Watkins, C.L. & Eng, J. J. (2014). Investigating measures of intensity during a structured upper limb exercise program in stroke rehabilitation: an exploratory study. *Archives of Physical Medicine and Rehabilitation*, 95, 2410-2419. doi: 10.1016/j.apmr.2014.05.025.

Duncan, P.W., Goldstein, L.B., Horner, R.D., Landsman, P.B., Samsa, G.P. & Matchar, D.B. (1994). Similar motor recovery of upper and lower extremities after stroke. *Stroke*, 25, 1181-1188.

Eng, X. W., Brauer, S., Kuys, S. S., Lord, M. & Hayward, K. S. (2014). Factors affecting the ability of the stroke survivor to drive their own recovery outside of therapy during inpatient stroke rehabilitation. *Stroke Research and Treatment*, Article ID 626538, 8 pages. doi: 10.1155/2014/626538.

Gebruers, N., Truijen, S., Engelborghs, S. & De Deyn, P. P. (2013). Predictive value of upper-limb accelerometry in acute stroke with hemiparesis. *Journal of Rehabilitation Research and Development.* 50, 1099-106. doi: 10.1682/JRRD.2012.09.0166.

Gladstone, D. J., Danells, C. J. & Black, S. E. (2002). The Fugl-Meyer assessment of motor recovery after stroke: a critical review of its measurement properties. *Neurorehabilitation and Neural Repair*, 16, 232-240.

Han, C., Wang, Q., Meng, P. P. & Qi, M. Z. (2013). Effects of intensity of arm training on hemiplegic upper extremity motor recovery in stroke patients: a randomized controlled trial. *Clinical Rehabilitation,* 27, 75-81.

Hayward, K. S. & Brauer, S. (2015). Dose of arm activity training during acute and subacute rehabilitation post stroke: A systematic review of the literature. *Clinical Rehabilitation*, 29, 1234-1243.

Hayward, K. S., Eng, J. J., Boyd, L. A., Lakhani, B., Bernhardt, J. & Lang, C. E. (2016). Exploring the role of accelerometers in the measurement of real world upper-limb use after stroke. *Brain Impairment*, 17, 16-33.

Kidd, D., Stewart, G., Baldry, J., Johnson, J., Rossiter, D., Petruckevitch, A. & Thompson, A. J. (1995). The Functional Independence Measure: a comparative validity and reliability study. *Disability and Rehabilitation*, 17, 10-14.

Kimberley, T.J., Samargia, S., Moore, L. G., Shakya, J. K. & Lang, C. E. (2010). Comparison of amounts and types of practice during rehabilitation for traumatic brain injury and stroke. *Journal of Rehabilitation Research and Development*, 47, 851-862.

Kleim, J. A. & Jones, T. A. (2008). Principles of experience-dependent neural plasticity: implications for rehabilitation after brain damage. *Journal of Speech, Language, and Hearing Research*, 51, S225-239.

Kong, K. H. & Lee, J. (2013). Temporal recovery and predictors of upper limb dexterity in the first year of stroke: A prospective study of patients admitted to a rehabilitation centre. *Neurorehabilitation*, 32, 345-350.

Krauker, J. W., Carmichael, S. J., Corbett, D. & Wittenberg, G. F. (2012). Getting neurorehabilitation right: what can be learned from animal model? *Neurorehabilitation Neural Repair*, 26, 923-931. doi: 10.1177/1545968312440745.

Kreisel, S. H., Bazner, H.& Hennerici, M. G. (2006). Pathophysiology of stroke rehabilitation: temporal aspects of neurofunctional recovery. *Cerebrovascular Diseases*, 21, 6-17.

Kwakkel, G., Kollen, B. J., van der Grond, J. & Prevo, A. J. (2003). Probability of regaining dexterity in flaccid upper limb: impact of severity of paresis and time since onset in acute stroke. *Stroke*, 34, 2181-2186.

Lang, C. E., MacDonald, J. R. & Gnip, C. (2007). Counting repetitions: an observational study of outpatient therapy for people with hemiparesis post-stroke. *Journal of Neurologic Physical Therapy*, 31, 3-10.

Lang, C. E., MacDonald, J. R., Reisman, D. S., Boyd, L., Jacobson Kimberley, T., Schindler-Ivens, S. M., Hornby, T. G., Ross, S. A. & Scheets, P. L. (2009). Observation of amounts of movement practice provided during stroke rehabilitation. *Archives of Physical Medicine and Rehabilitation*, 90, 1692-1698. doi: 10.1016/j.apmr.2009.04.005.

Lang, C. E., Wagner, J. M., Edwards, D. F. & Dromerick, A. W. (2007). Upper extremity use in people with hemiparesis in the first weeks after stroke. *Journal of Neurologic Physical Therapy*.31, 56-63.

Lincoln, N.B., Jackson, J.M. & Adams, S.A. (1998). Reliability and Revision of the Nottingham Sensory Assessment for Stroke Patients. *Physiotherapy* 84, 358-365.

Nakayama, H., Jorgensen, H. S., Raaschou, H. O. & Olsen, T. S. (1994). Recovery of upper extremity function in stroke patients: The Copenhagen Stroke Study. *Archives of Physical Medicine and Rehabilitation*, 75, 394-398.

Narai, E., Hagino, H., Komatsu, T. & Togo, F. (2016). Accelerometer-based monitoring of upper limb movement in older adults with acute and subacute stroke. *Journal of Geriatric Physical Therapy*, 39, 171-177. doi: 10.1519/JPT.0000000000000067.

Rand, D. & Eng, J. J. (2012). Disparity between functional recovery and daily use of the upper and lower extremities during subacute stroke rehabilitation. *Neurorehabilitation and Neural Repair*, 26, 76-84.

Rangaraju, S., Frankel, M. & Jovin, T.G. (2016). Prognostic value of the 24-hour neurological examination in anterior circulation ischemic stroke: A post hoc analysis of two randomized controlled stroke trials. *Interventional Neurology*, 4, 120-129.

Rand, D. & Eng, J. J. (2010). Arm-hand usage in healthy older adults. *American Journal of Occupational Therapy*, 64, 877-885.

Rand, D., Givon, N., Weingarden, H., Nota, A. & Zeilig, G. (2014). Eliciting upper extremity purposeful movements using video games: a comparison with traditional therapy for stroke rehabilitation. *Neurorehabilitation and Neural Repair*, 28, 733-739. doi: 10.1177/1545968314521008.

Shim, S., Kim, H. & Jung, J. (2014). Comparison of upper extremity motor recovery of stroke patients with actual physical activity in their daily lives measured with accelerometers. *Journal of Physical Therapy Science*, 26, 1009-1011.

Singapore Ministry of Health (2017). Admission for stroke; no serious complications from 1 July 2016 to 30 June 2017.Retrieved from https://www.moh.gov.sg/content/moh_web/home/costs_and_financing/hospital-charges/Total-Hospital-Bills-By-condition procedure/Neurological_Stroke.html Accessed 8 Dec 2017

Urbin, M. A., Waddell, K. J. & Lang, E. (2015). Acceleration metrics are responsive to change in upper extremity function of stroke survivors. *Archives of Physical Medicine and Rehabilitation*, 96, 854-861.

Uswatte, G., Giuliani, C., Winstein, C., Zeringue, A., Hobbs, L. & Wolf, S. L. (2006). Validity of accelerometry for monitoring real-world arm activity in patients with subacute stroke: evidence from the extremity constraint-induced therapy evaluation trial. *Archives of Physical Medicine and Rehabilitation*, 87, 1340-1345.

Uswatte, G., Wolfgang, H. R. M., Foo, B., Varma, M., Moran, S. & Taub, E. (2000). Objective measurement of functional upper-extremity movement using accelerometer recording transformed with a threshold filter. *Stroke*, 31: 662-667.

Woodbury, M. L., Velozo, C. A., Richards, L. G. & Duncan, P. W. (2013). Rasch analysis staging methodology to classify upper extremity movement impairment after stroke. *Archives of Physical Medicine and Rehabilitation*, 94, 1527-1533.

Table 1. Characteristics of study population. Reported as median (IQR) unless otherwise stated.

	Mild (n=5)	Moderate (n=3)	Severe (n=4)
Age (years)	65 (12)	54 (11)	62 (6)
Gender (male), n (%)	4 (80)	1 (33)	2 (50)
Diagnosis (infarct), n (%)	3 (60)	2 (67)	2 (50)
Time post -stroke (days)	20 (5)	13 (9)	22 (4)
Time spent in rehabilitation (days)	7 (4)	5 (7)	10 (8)
Right-hand dominant, n (%)	5 (100)	3 (100)	3 (75)
Right side affected, n (%)	1(20)	2(67)	1(50)
Dominant side affected, n (%)	1 (20)	2 (67)	2 (50)
National Institute of Health Stroke Scale (NIHSS score /44)	3 (2)	6 (2)	12 (5)
Montreal Cognitive Assessment (MoCA score /30)	26 (2)	23 (4)	16 (3)
Functional Independence Measure Total (FIM score /126)	114 (39)	73 (27)	60 (10)
Functional Independence Measure Self Care (FIM score /42)	39 (18)	26 (10)	20 (3)
Functional Independence Measure Transfer (FIM score /21)	18 (9)	12 (3)	9 (2)
Functional Independence Measure Mobility (FIM score /14)	10 (7)	4 (3)	3 (1)
Nottingham Sensory Assessment (NSA score /84)	81 (1)	72 (29)	8 (12)
Fugl Meyer Upper Limb Assessment (FMUL score /66)	65 (10)	32 (3)	5 (4)
Grip force (kg)	19 (13)	2 (2)	0 (0)
Lateral pinch (kg)	6 (1)	1 (2)	0 (0)
Duration of occupational therapy session (minutes)	0 (60)	80 (5)	52 (18)

Duration of physiotherapy session (minutes)	50 (10)	70 (15)	78 (32)

Table 2. Accelerometry outcomes throughout 24 hours, during occupational therapy (OT) sessions, physiotherapy (PT) session, outside therapy. Reported as median (IQR).

	24 hours	During OT Sessions	During PT Sessions	Outside Therapy sessions
Mild, n=5	n=5	n=2	n=5	n=5
Paretic UL duration (hours)	5.44 (1.71)	0.79 (0.12)	0.33 (0.15)	4.92 (2.18)
Non-paretic UL duration (hours)	8.72 (0.67)	0.69 (0.38)	0.57 (0.09)	7.99 (1.45)
Use ratio	0.59 (0.21)	1.50 (0.64)	0.81 (0.36)	0.58 (0.24)
Median magnitude ratio	-2.79 (2.14)	3.30 (3.70)	-0.74 (1.60)	-2.98 (3.22)
Median bilateral magnitude	83.44 (45.44)	69.62 (32.00)	80.05 (64.36)	84.00 (43.03)
Variation ratio	0.62 (0.19)	0.82 (0.40)	0.59 (0.34)	0.62 (0.37)
Moderate, n=2	n=2	n=2	n=2	n=2
Paretic UL duration (hours)	4.10 (2.23)	0.46 (0.05)	0.56 (0.19)	3.08 (2.10)
Non-paretic UL duration (hours)	8.52 (3.46)	0.56 (0.04)	0.73 (0.30)	7.23 (3.12)
Use ratio	0.45 (0.80)	0.92 (0.18)	0.92 (0.05)	0.37 (0.13)
Median magnitude ratio	-5.25 (1.75)	-0.37 (0.61)	-0.81 (0.65)	-5.78 (1.22)
Median bilateral magnitude	58.66 (14.29)	168.04 (29.44)	62.59 (37.57)	59.41 (13.24)

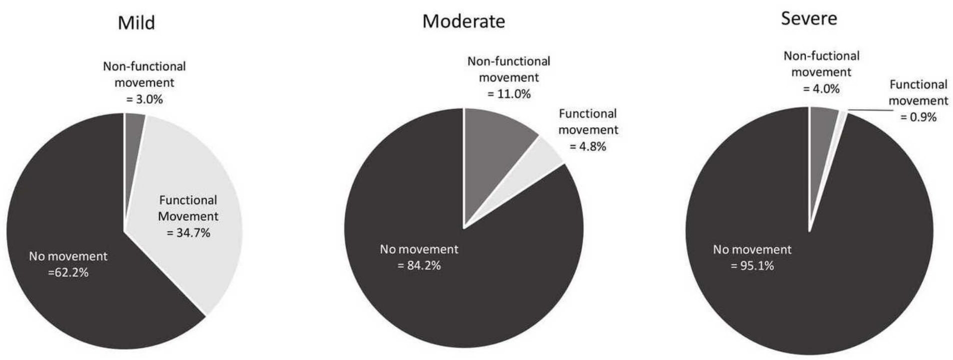
Variation ratio	0.57 (0.08)	1.04 (0.22)	0.66 (0.19)	0.49 (0.14)
Severe, n=4	n=4	n=4	n=4	n=4
Paretic UL duration (hours)	1.49 (0.20)	0.19 (0.08)	0.36 (0.35)	1.06 (0.13)
Non-paretic UL duration (hours)	7.10 (2.86)	0.38 (0.22)	0.46 (0.18)	5.97 (3.15)
Use ratio	0.22 (0.12)	0.72 (0.72)	0.64 (0.39)	0.15 (0.04)
Median magnitude ratio	-7.00 (0.00)	-3.82 (6.52)	-2.22 (4.41)	-7.00 (0.00)
Median bilateral magnitude	54.53 (9.18)	62.53 (26.17)	40.13 (10.07)	54.69 (6.02)
Variation ratio	0.35 (0.10)	0.35 (0.55)	0.78 (0.34)	0.30 (0.05)

Table 3. Mean duration of different types of upper limb (UL) activities across 12-hours observation (including occupational, physiotherapy sessions and outside therapy). Reported in minutes (% of 12 hours).

	Mild, n=5	Moderate, n=3	Severe, n=4
Non-functional UL activities			
Passive stretching	1 (0.1%)	15 (2.3%)	17 (2.5%)
Active-assisted exercises	3 (0.5%)	37 (5.6%)	0 (0.1%)
Active/ strengthening Exercises	17 (2.5%)	9 (1.4%)	0 (0.0%)
Passive positioning	0 (0.0%)	11 (1.7%)	9 (1.4%)
Functional UL activities			

Simulated/ actual functional activities	96 (14.3%)	23(3.6%)	6 (0.9%)
Basic activities of daily living	54 (8.0%)	5 (0.7%)	0 (0.0%)
Instrumental activities of daily living	46 (6.9%)	3 (0.4%)	0 (0.0%)
Leisure/ hobbies	37 (5.6%)	0 (0.1%)	0 (0.0%)
No UL movement	416 (62.2%)	548 (84.2%)	652 (95.2%)

a)



PRI_1784_F1a.jpg

b)

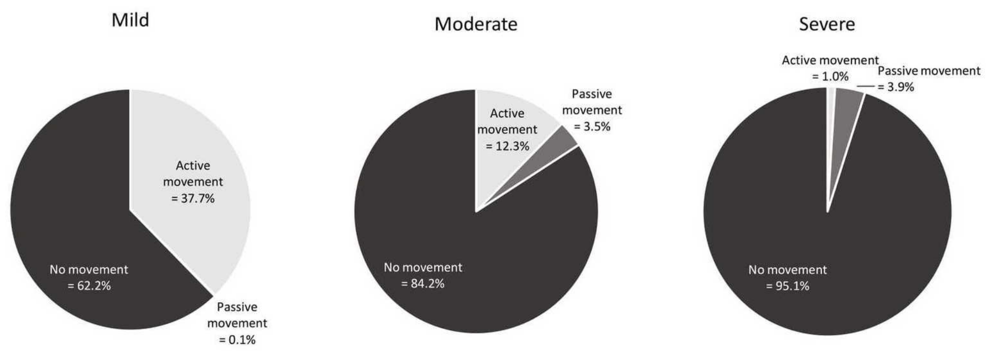


Fig 1 Paretic upper limb movement throughout the 12 hours observation across UL severity levels of mild, moderate and severe for a) functional, non-functional movements and no movement, and b) active, passive movement and no movement.

PRI_1784_F1b.jpg

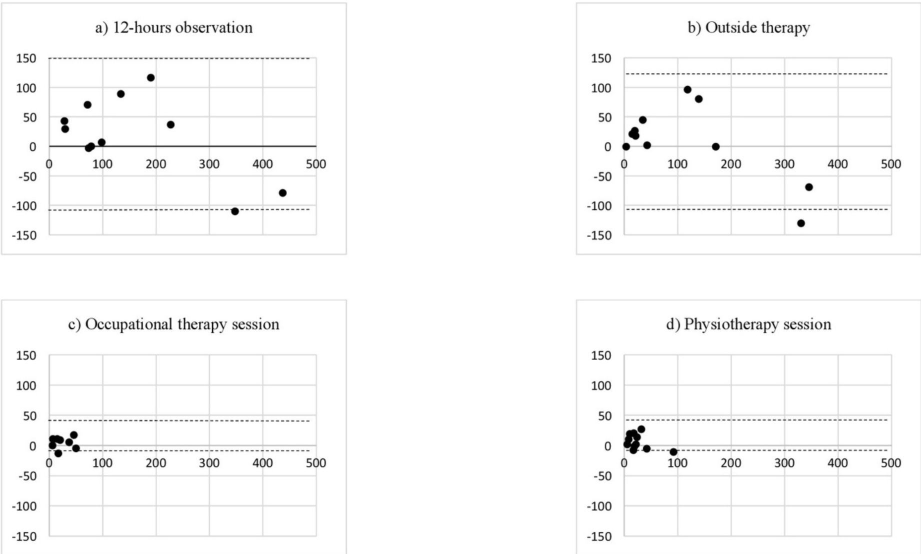


Fig 2 Bland- Altman plots for accelerometry and observation findings
Y-axis: difference between accelerometry and observed measurements (mins); x-axis: mean of accelerometry and observed measurements (mins) for a) 12-hours observation, b) outside therapy sessions, c) occupational therapy session, and d) physiotherapy session. Dashed lines represent upper and lower limits of agreement.

PRI_1784_F2.jpg