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Investigating measures of intensity during a structured upper limb exercise programme in stroke rehabilitation: An exploratory study

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Abstract

Objectives—To use three measures of intensity (i) time, (ii) observed repetitions and (iii) wrist accelerometer activity counts to describe the intensity of exercise carried out when completing a structured upper limb exercise programme. To explore if a relationship exists between wrist accelerometer activity counts and observed repetitions.

Design—Observational study design.

Setting—Rehabilitation centre research laboratory.

Participants—Thirteen community dwelling stroke survivors with upper limb hemiparesis.

Intervention—Not applicable.

Main Outcome Measures—Time engaged in exercise, total repetitions and accelerometer activity counts for the affected upper limb.

Results—Mean session time was 48.5 minutes (SD 7.8 minutes). Participants were observed to be engaged in exercises for 63.8% (SD 7.5%) of the total session time. The median number of observed repetitions per session was 340 (IQR 199–407) of which 251 (IQR 80–309) were purposeful repetitions. Wrist accelerometers showed the stroke survivors' upper limbs to be moving for 75.7% (SD 15.9%) of the total session time. Purposeful repetitions and activity counts were found to be significantly correlated (r_s=0.627, p<0.05).

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Conflicts of interest
None declared

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Conclusions—Stroke survivors were not actively engaged in exercises for approximately one third of each exercise session. Overall session time may not be the most accurate measure of intensity. Counting repetitions was feasible when using a structured exercise programme and provides a clinically meaningful way of monitoring intensity and progression. Wrist accelerometers provided an objective measure for how much the arm moves, which correlated with purposeful repetitions. Further research using repetitions and accelerometers as measures of intensity is warranted.

Keywords

Stroke; rehabilitation; time; repetitions; accelerometer

Every year, 15 million people worldwide suffer a stroke[1]. Two thirds of stroke survivors achieve independent ambulation after stroke, but less than half recover upper limb function at six months[2]. Best evidence for improving functional recovery after stroke suggests rehabilitation should consist of high intensity repetitive task-specific practice[3–6]. However despite this, the amount of therapy time dedicated to upper limb rehabilitation remains low[7] and upper limb exercises, when prescribed, are often of low intensity[8].

Therapists working in stroke rehabilitation are being challenged to find new ways of increasing the intensity of practice that stroke survivors engage in each day[7] with suggested strategies including self-administered exercise[9], group exercise[10] and family assisted exercise[11]. Despite the strength of evidence supporting intensity, objectively quantifying intensity of therapy in stroke rehabilitation remains problematic. It is difficult to determine and increase intensity, without first having robust, feasible methods to be able to measure intensity during rehabilitation.

Time continues to remain the dominant measure of intensity both in research[7, 12] and in clinical guidelines[13, 14]. It is the measure used to synthesize data in meta-analyses[3, 12, 15] and is the standard by which clinicians and services are evaluated[16]. However it has been recognised that time is a proxy measure for intensity and provides a rather crude estimate[17]. It does not give an indication of the actual amount of movement, or the types of movement, that take place during a particular session[18]. It has recently been reported that people with stroke are inactive for an average of 40% of their physical therapy sessions[7]. In addition, therapists' tend to overestimate the time they spend with patients[19]. Therefore, there is a clear need for alternative measures to quantify intensity.

One alternative measure is number of repetitions. Although repetitions have been used as measures of intensity in animal studies that examine neuroplasticity[20, 21], the use of repetitions is less frequent within rehabilitation research and practice. Lang and colleagues have used repetitions to quantify the intensity of upper limb exercise that occurs during rehabilitation[22], and during inpatient hospital stays after stroke[23]. However, these observational studies focused on routine therapy sessions where many challenges in categorising the content, and hence intensity of these sessions, have arisen[22, 24]. Repetitions have also been used in research of robot- assisted therapy[25] and video games[26]. The clinical utility of using repetitions to measure intensity of practice during structured exercise programmes has not been investigated. Wrist accelerometers are another alternative method used by researchers attempting to quantify the intensity of upper limb exercise[22, 23] and have been used to measure arm-hand usage when a patient is on the stroke rehabilitation unit[27].

This study will use three measures of intensity (i) time, (ii) repetitions and (iii) wrist accelerometers to describe the intensity of exercise carried out during a session using the Graded Repetitive Arm Supplementary Program (GRASP). GRASP is a self-directed and structured upper limb exercise programme which has been shown to be effective in improving upper limb recovery in sub-acute stroke[9]. As the content of this exercise programme is already defined, it will be possible to more accurately define observed repetitions. A second objective of the study is to determine whether accelerometer data is a meaningful measure in clinical practice by exploring the relationship between wrist accelerometer activity counts and observed repetitions. To our knowledge this is the first study to have explored the use of time, repetitions and accelerometer simultaneously for measuring intensity during a structured upper limb exercise programme.

METHODS

Participants

Thirteen community dwelling stroke survivors who i) could understand and speak English and ii) had upper limb hemiparesis ranging from 2–5 on the REACH Scale[28] were recruited to take part in this study. Billingham and colleagues argue that all studies should have a sample size justification, but not necessarily a sample size calculation[29]. The purpose of our study was to establish measures of intensity using a structured exercise programme and it has been suggested that a sample of twelve provides a sufficiently precise estimate of the mean/variance[30]. The REACH Scale is a 6 point classification scale that captures affected upper limb use outside of the clinical setting. The scale consists of two separate classification scales for people who have had their dominant and non-dominant side affected by the stroke. An algorithm is used to assist in identifying the patient's REACH score which ranges from 0 (no use/exercise only), 1 (stabilize only), 2 (provide assistance to unaffected side/easy reaching tasks), 3 (some reach and grasp with hand manipulation), 4 (everyday use unless potential negative consequences) and 5 (full use). Potential participants were identified from a database of stroke survivors who had previously been involved in research studies with the rehabilitation centre and had agreed to be contacted about involvement in future research. Participants who attended to take part in the research provided written informed consent prior to taking part in the study and received a $25 Canadian honorarium to compensate them for their time.

Setting

Data collection took place in the research laboratory of the rehabilitation centre.

Data Collection

Each participant was observed for a single session completing the GRASP. Observations were carried out by two chartered physiotherapists. A data collection form (Appendix I: Data collection form) was used to document repetitions. Total session time and time spent completing each exercise was measured using a stopwatch. Prior to data collection, both physiotherapists agreed on what would be counted as a single repetition for each of the GRASP exercises (Appendix II: Definitions of repetitions for GRASP exercises). The exercises were categorised as passive, active non-purposeful, resisted and purposeful exercises. Purposeful exercises included exercises which had a purpose i.e. were either task-oriented (dropping and catching a ball) or reflective of activities of daily living (taking the lid of a jam jar). Active exercises were exercises that did not have a purpose e.g. lifting the arm up in front, or bringing the arm out to the side. When these active non-purposeful exercises were conducted with a weight they were categorised as resisted exercises. Observed repetitions from both sets of data collection forms were extracted into SPSS to analyse inter-rater reliability (IRR). As number of repetitions were ordinal level data the interclass correlation coefficient was used to assess IRR as advised by Hallgren[31]. An ICC of 0.968 indicated substantial reliability between raters. Discrepancies detected between the data collection forms in all cases could be resolved by consulting the definitions of repetitions e.g. one rater counted putting the lid on the jam jar and removing it as one repetition where it had been agreed a priori that this would be counted as two separate repetitions. Total number of repetitions for each participant was summed as were repetitions for each of the categorisations.

Prior to commencing the session, participant characteristics were noted and an Actical® accelerometer was placed on both wrists of the participant. The marker button on the accelerometers was pressed at the beginning and end of the session to ensure only activity counts during the exercises session were recorded. The Actical accelerometer is a small (28×27×10 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. The Actical® accelerometer has been shown to have the best intra- and inter-instrument reliability compared to two other commonly used models[32]. Data were downloaded from the activity monitors using a serial port computer interface and the Actical® software, and exported into an Excel spread sheet. Data outside of the marker points, indicating the beginning and end of the exercise session, were removed from the data set. The activity counts were summed for both affected and unaffected upper limbs. The amount of time that the upper limb was active during the session was calculated by filtering out epochs during which no activity counts were recorded and summing the epochs during which activity counts were recorded. The percentage of time that upper limb activity occurred was then calculated.

Data Analysis

Microsoft Excel® and PASW Statistics 20 were used for data management and analysis. Descriptive statistics and frequencies were used to summarise the data. The Shapiro-Wilk test showed the interval level data (time, activity counts) to be normally distributed and means and standard deviations were generated for these variables. Medians and interquartile ranges were generated for ordinal level data (repetitions). Spearman's rank correlation coefficient was used to examine correlations between accelerometer activity counts and repetitions, as repetitions were ordinal level data. A significance value of $p < 0.05$ was set.

Ethical Approval

This study was approved by the relevant university research ethics boards.

RESULTS

Participant characteristics are shown in Table 1.

Table 2 shows descriptive statistics for the individual categories. Mean session time was 48.5 minutes (SD 7.8 minutes) of which the stroke survivor was actively engaged in exercises for 31.2 minutes (SD 7.4 minutes) or 63.8% (SD 7.5%). The activity monitors showed stroke survivors to be active for 75.7% (SD 15.9%) of the session. Median number of observed repetitions per session was 340 (IQR 199–407) of which 251 (IQR 80–309) were purposeful repetitions. Three participants had an ARAT score of <10 indicating severe upper limb impairment. The total repetitions that these participants completed during the session were 173, 112 and 176 of which 57, 45 and 87 were purposeful repetitions respectively. The affected side activity counts were 3912, 13345 and 6686 and the non-affected side activity counts were 7054, 10029 and 13299 respectively.

As can be seen in Table 2, there were insufficient numbers of passive, active non-purposeful and resisted repetitions for these to be included in the correlation analysis. Total repetitions and accelerometer activity counts were found not to be significantly correlated (r_s=0.352, p=.239). Figure 1 shows a scatterplot for the sub-category of purposeful repetitions and accelerometer activity counts where a significant correlation was detected (r_s=0.627, p=0.022).

DISCUSSION

This study used three measures to describe the intensity of exercise carried out during a structured upper limb exercise programme; time, repetitions and activity counts using wrist accelerometers. The strengths, weaknesses and relationships between these measures will now be discussed, and implications for research and practice considered.

Time

Time was easy to measure and demonstrated that stroke survivors were found to be actively engaged in exercises for approximately two thirds of the GRASP sessions. This finding is reflective of a recent systematic review which also identified stroke survivors to be physically active for on average 60% of their physiotherapy sessions[12]. It is important to note that as the sessions in this study consisted solely of completing the GRASP exercises, and did not include other activities (e.g. goal setting, carer training, outcome measures) that this figure is likely to overestimate the amount of time stroke survivors are engaged in active exercise during therapy sessions in day to day clinical practice. This is an important finding for future guidelines as currently there is often a focus on provision of therapy for a particular time, e.g. 45 minutes in the UK[13], as opposed to the amount of time during which active exercise is taking place. Evidently if we want to achieve, for example 40 minutes of active exercise, we need to be allocating 60 minutes of session time. If therapists are to use time as a measure of practice intensity, they should consider measuring time being active completing the exercises as well as overall session time. Our findings also have implications for research as interventions are often described by overall therapy time and not the time engaged in active exercises. Care needs to be taken when using time as a measure of intensity in dosing studies and systematic reviews.

Repetitions

This study explored the number of repetitions undertaken by stroke survivors during a GRASP session. Reflective of normal therapy sessions, in this study the types of repetitions were graded to match participants' ability. As can been seen by participants' REACH scores and grip strength values, the majority of participants were of higher levels of ability. Not surprisingly, purposeful repetitions were the most prominent sub-category of repetitions. Counting repetitions was feasible due to the use of a priori defined repetitions within a structured programme. Accordingly we found substantial reliability between different raters observing each exercise session. We would anticipate that if exercises are prescribed in this structured way (i.e. sets and reps), that it would be feasible for stroke survivors to monitor their completed repetitions (with the assistance of family/carers/rehabilitation assistants where possible) for the therapist to review. This is supported by the findings from a small study by Scrivener and colleagues who found that therapist-selected patients were able to count repetitions reliably when completing structured exercise programmes during in-patient rehabilitation[33].

Despite the wide range in the number of repetitions per session, even the lowest observation (112 repetitions, of which 45 were purposeful) was significantly higher than the average number of repetitions reported in previous studies e.g. 32 (95% CI 20–44)[18]. Lang and colleagues have found the numbers of purposeful or task-specific movements to be lowest of three categories of upper limb exercises prescribed during observed therapy sessions (39 repetitions for active-exercise movements, 34 for passive-exercise movements, 12 for purposeful movements)[22]. Interestingly, a recent study by Rand and colleagues found comparable numbers of purposeful repetitions using video games for upper limb stroke rehabilitation to those found in this study[26]. They reported a median of 271 purposeful movements in the video game group (n=15) compared to 48 purposeful movements in the usual care group (n=14). Such studies provide further evidence that counting repetitions is feasible, and could enable comparison across more studies in systematic reviews. It arguably gives a better reflection of intensity than time, though does still have some limitations. Repetitions do not indicate if the task was challenging or not, or the speed or quality of movement. One repetition of one task does not equate to one repetition of another (e.g. how does turning over a coin equate to throwing and catching a ball?). However further use within the research and clinical context is warranted.

Wrist accelerometer

Upper limb activity during the GRASP session was recorded as activity counts using wrist accelerometers. Mean activity counts for the affected side were 18092 (SD 9848). Previous studies also using Actical® accelerometers have found less activity counts during therapy sessions. Rand and Eng reported a median of 2411 activity counts (IQR 635–6848) during an in-patient occupational therapy session, and 2744 (IQR 927–5960) during a physical therapy session[27]. The usual care group of a study exploring purposeful repetitions using video games completed a median of 14872 activity counts (IQR 9932–23 747)[26]. The participants in the video game group in this study (n=15) performed a median of 37 970 activity counts (IQR 12 833–67031). The increased activity counts for the video games perhaps demonstrates that the movements within these games were faster, and highlights that the accelerometers only measure movement and not the type or quality of the movement.

Wearing accelerometers and pressing the markers at the start and the end of the exercise session was feasible. However, the cost and analysis of the equipment means that clinical utility is currently limited[34]. The accelerometers used in this study collect data in the form of activity counts during a set time period e.g. every fifteen seconds. This data could be used to calculate upper extremity use over longer periods of time, (e.g. 24 hours) and such a measure could prove clinically useful. It is important to note however that these accelerometers do not differentiate active versus passive movement and as a result may potentially overestimate the amount of upper limb activity which is taking place. As can been seen in the results, the percentage time actively engaged in exercise was 63.8% based on raters' observation in comparison to 75.7% of the time spent active when measured by the accelerometer.

Activity counts were moderately correlated with purposeful exercise repetitions. This result echoes that of Rand and colleagues who also found significant high and moderate correlations between the repetitions of purposeful movement to activity counts[26]. There is no gold standard criterion measure of intensity, with the predominant measure of time having the limitations noted above. However, the significant correlation between activity counts and purposeful exercise repetitions does demonstrate these measures have concurrent validity, in addition to face validity. Thus, accelerometers may provide a valuable measure of activity with stroke survivors that are engaged predominantly in purposeful activity. However, total activity counts and total repetitions were not found to be significantly correlated in this study. This suggests that non-purposeful repetitions and purposeful repetitions may be detected differently by the accelerometer. As the counts for exercises other than purposeful exercises were so low this needs further investigation. Accelerometers may be less useful in more severely impaired patients who have more passive movement of their impaired upper limb and move slower. The clinical utility of accelerometers among patients with more severe upper extremity impairments needed further examination however due to the small numbers in this study.

Study Limitations

This was an exploratory study and as such the study sample, though justified, was small and comprised of community dwelling stroke survivors who were on average 8.5 years after their stroke. Only three participants' had severe upper limb impairment. Therefore further research is needed on a larger sample, particularly on a subgroup of severely impaired patients to determine the usefulness of accelerometers. It is also important to note that this study consisted of an hour long session focused solely on upper limb exercise; this should be taken into account when comparing repetitions and activity counts in previous observational studies were repetitions of individual movements were counted as opposed to repetitions of whole exercises.

CONCLUSIONS

This exploratory study found that stroke survivors were not actively engaged in exercises for approximately one third of the exercise session and time therefore may not be the most accurate measure of intensity in stroke rehabilitation. Counting and documenting repetitions is feasible when using a structured exercise programme and provides a clinically meaningful way of monitoring intensity and progression. Activity monitors provide an objective measure for how much the arm moves. Activity counts related to purposeful movement and thus provide preliminary support for their validity. More research using repetitions and accelerometers as measures of intensity is warranted.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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ABREVIATIONS

GRASP	Graded Repetitive Arm Supplementary Program
REACH	Rating of Everyday Arm-use in the Community and Home
ARAT	Action Research Arm Test

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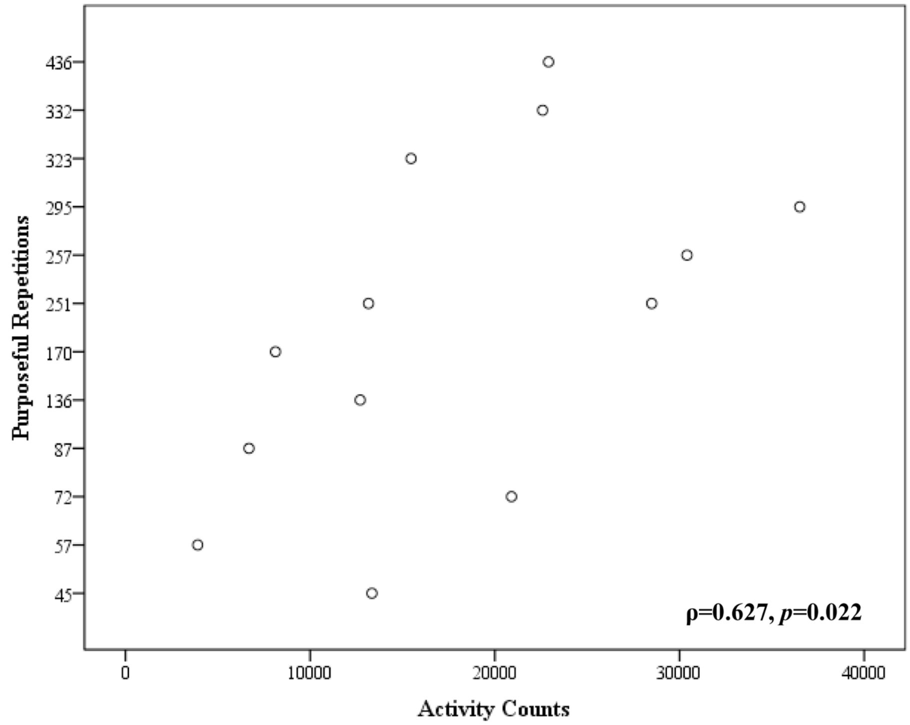

Figure 1.

Spearman's Rank correlation coefficient for purposeful repetitions and accelerometer activity counts (ρ)

Table 1

Participant characteristics

Gender	Age (yrs)	Time since stroke (yrs)	REACH* Score	ARAT†	Hand dominance	Affected upper limb	Grip strength affected hand (kg)	Grip strength non-affected hand (kg)
F	56.4	12.5	2	4	Right	Right	4	18
F	72.9	15.3	2	7	Right	Left	2	22
M	70.1	5.8	2	9	Right	Left	5	50
F	72.7	10.5	3	34	Right	Right	18	30
M	65.6	4.8	3	42	Right	Left	22	42
M	64.6	7.6	3	48	Right	Right	38	48
M	75.5	5.0	3	56	Right	Right	36	46
M	62.5	13.4	3	37	Right	Left	48	70
M	76.7	12.6	4	55	Right	Right	31	36
M	72.9	4.3	4	56	Right	Right	42	34
F	83.7	8.7	4	57	Right	Right	24	17
F	61.5	2.8	4	57	Right	Right	26	23
M	69.4	7.6	4	57	Right	Left	32	38

*Rating of Everyday Arm use in the Community and Home scale

†Action Research Arm Test

Table 2

Descriptive statistics

Observed Measurements (time)		
Categories	**Mean**	**SD**
Session duration (min)	48.5	7.8
Time engaged in exercises (min)	31.2	7.4
Time engaged in exercises (% of total time)	63.8	7.5

Observed Measurements (repetitions)		
Categories	**Median**	**IQR**
Total repetitions	340	199–407
Passive	2	0–9
Active non-purposeful	5	0–58
Resisted	70	18–108
Purposeful	251	80–309

Actical® Activity Monitor Measurements		
Categories	**Mean**	**SD**
Affected side activity counts	18092.15	9847.82
Non-affected side activity counts	9440.31	4217.84
Session duration (min)	48.2	8.9
Time active in session (min)	35.9	6.9
Time active in session (% of total time)	75.7	15.9