Reliability of Dynamic Muscle Performance in the Hemiparetic Upper Limb

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ABSTRACT

We established reliability of upper-limb muscle performance in adults with post-stroke hemiparesis. Ten adults with post-stroke hemiparesis (51.5 ± 34.5 months) performed isokinetic concentric shoulder flexion, elbow flexion, and extension at 3 criterion speeds (30°/s, 75°/s, and 120°/s) on 3 separate occasions (Days 1, 7, and 49). As several participants were unable to reach criterion speeds, actual speed and power were also analyzed. Relative reliability (intraclass correlation coefficient-ICC) was excellent for torque and power (0.82 to 0.98) but less consistent for speed (0.63 to 0.99). Absolute reliability (standard error of measurement-%SEM) ranged between 0% to 34%. No systematic errors were observed across sessions. Smallest real differences (SRD) ranged between 4-11Nm for torque and 3-24W for power. Shoulder flexion, elbow flexion, and elbow extension torque, speed, and power can be measured reliably following stroke. Given that many of these individuals demonstrate inability to generate torque at preselected speeds, power may be a more valid indicator of muscle performance.

Key Words: stroke, hemiplegia, reliability, weakness, upper extremity, rehabilitation, evidence-based medicine

INTRODUCTION

Muscle weakness is one of the most common impairments following stroke[1] and it has been shown to relate significantly to motor function of both the upper[2,3] and lower[4-6] limbs. Muscle strength has been defined as the ability to generate muscular force[1,7] and is commonly quantified objectively by measuring torque during isometric contractions. However, given the dynamic nature of functional tasks, it is also important to include the assessment of muscle performance under dynamic conditions required by isotonic or isokinetic contractions.

To quantify this common impairment in persons with post-stroke hemiparesis, reliable measures of muscle strength are necessary. Several studies have investigated the reliability of muscle strength under both isometric[8,9] and isokinetic[10-14] conditions in the hemiparetic lower limb and demonstrated that torque production can be measured reliably in this population. In fact, test-retest reliability of the contralesional limb has been shown to be as high as in the ipsilesional limb for flexion and extension motions of the hip, knee, and ankle joints across several levels of movement speed conditions.[10-14]

In contrast, the reliability of the hemiparetic upper limb has not been well established. Bohannon and associates[9,15] have examined the test-retest reliability of isometric strength tested with a hand-held dynamometer in the hemiparetic upper limb of individuals with neurological disorders. They found that the intra-rater reliability of shoulder, elbow, and wrist movements was high (Pearson product-moment correlations of 0.97-0.98) with only shoulder abduction resulting in significant differences ($P < 0.01$) between repeated measures as indicated by ANOVA.[15] When testing the interrater reliability of 3 upper limb motions, however, they found that the reliability was not as strong, ie, relative reliability was good to high (Pearson product-moment correlations of 0.84-0.94) but t-tests revealed significant differences between the 2 raters' measures for 2 (shoulder external rotation and wrist extension) of the 3 motions tested.[9] To our knowledge, no study has addressed the test-retest reliability of muscle performance under dynamic conditions in the upper limbs of persons with post-stroke hemiparesis. As functional activities often demand performance under concentric and eccentric conditions, the assessment of dynamic muscle strength may be more relevant when measuring functional muscle performance.

It is known that in addition to reduced magnitude, speed-dependent properties of torque development are impaired following stroke. For example, there is an increase in the time to generate peak isometric torque of the contralesional upper limb muscles[16,17] as well as specifically the knee extensors[8,18,19] of the lower limb in persons with post-stroke hemiparesis. Similarly, it has been found that during isokinetic concentric contractions, movement speed has a greater effect on the strength of the contralesional elbow muscles than of the ipsilesional limb. That is, a greater strength deficit is evident on the contralesional side with increasing movement speed.[20] Furthermore, these speed-dependent impairments of muscle contraction have been shown to relate to function.[18,20] It is therefore clear that speed is an important factor to consider when measuring muscle performance following stroke.

The purpose of this study was to determine the test-retest reliability of muscle performance during isokinetic

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testing of shoulder flexion, elbow flexion, and elbow extension of both the contralesional and ipsilesional limbs of persons with post-stroke hemiparesis. Shoulder flexion, elbow flexion, and elbow extension were selected to represent upper limb muscle performance, as these movements are an integral part of everyday function such as reaching, feeding, and dressing. Three different movement speeds (30º/s, 75º/s, and 120º/s) were tested and 3 variables of muscle performance (torque, actual speed, and power) were examined. In addition to the relative (as measured by the intraclass correlation coefficient [ICC]) and absolute (as measured by the measurement error) reliability, we quantified the minimum magnitude of change (smallest real difference [SRD]) that would constitute a real change in performance. Because measures of muscle performance are commonly used both in cross-sectional studies as well as in intervention studies, we determined the reliability of these measures across a 7-week time interval. We hypothesized that the reliability of upper limb muscle performance would be good, comparable to values found in previous lower limb studies.[10-13]

METHODS

Participants

Ten adults with post-stroke hemiparesis of greater than 6 months duration were recruited from the community. Criteria for participation included: (1) clinical presentation of a single unilateral stroke, (2) absence of pain or contracture in the upper limbs, (3) no more than minor impairment of upper-limb sensation or proprioception (as evaluated by the sensation component of the Fugl-Meyer,[21] ie, minimum score of 1 for both light touch and proprioception), (4) ability to comprehend and follow 3-step commands as evidenced on the Cognistat examination,[22] and (5) demonstration of at least 30º of active elbow flexion and 10º to 15º of active shoulder flexion against gravity. The study was approved by the local university's Administrative Panel on Human Subjects in Medical Research and all participants provided informed consent in accordance with the Declaration of Helsinki. Participant characteristics are presented in Table 1.

Table 1. Participant Characteristics (N=10)

	Mean	SD	Range
Age (yr)	62.2	12.0	52.0-81.0
Time since onset of stroke (mo)	51.5	34.5	13.5-116.8
Upper-limb Fugl Meyer Scores*	36.0	15.5	16.0-62.0
Gender	Male/Female		5/5
Side Affected	Right/Left		5/5

* Only the motor function portion of the upper-limb Fugl-Meyer[21] test is reported (maximum score= 66).

Instrumentation

The dynamometer used to assess the performance of elbow flexors, elbow extensors, and shoulder flexors was the commercially available Biodex System (3.0 Pro, Shirley, New York, NY). The instrument was calibrated prior to the experiment both by following the protocol described in the Biodex operation manual as well as by hanging calibrated weights. During all test sessions, participants were seated in the Biodex chair with the back angled at 85º, stabilized by trunk and waist straps, and feet supported with a leg rest. Biodex settings for each participant were recorded for consistency of positioning across sessions.

For elbow flexion and extension, a modified elbow attachment with a prefabricated wrist splint was used to provide wrist and hand support.[23] This modified elbow attachment was used for both the ipsilesional and contralesional arms. The upper arm was stabilized on a padded support attached to the Biodex seat and the shoulder was positioned in 45º of flexion and 5º of abduction. The lateral epicondyle of the humerus was aligned with the axis of rotation of the Biodex system. The elbow actions were tested through 120º range of motion in the sagittal plane. The starting position for testing elbow flexion was 0º of elbow extension and for testing elbow extension was 120º of elbow flexion.

For shoulder flexion, the dynamometer's axis of rotation was aligned with the tip of the acromion process on the side being tested. A custom fabricated trough with an adjustable cone for handgrip was used to stabilize the arm. This trough was used for both the contralesional and ipsilesional arms. Shoulder flexion range of motion limits were set from neutral (arm by the side of the body) to 90º of flexion. The testing began with the arm in 0º of shoulder flexion and abduction with adjustments made as necessary for participant comfort and to allow the trough to clear the body (Figure 1).

Figure 1. Dynamometer configuration and positioning for shoulder flexion. The arm was stabilized with a custom fabricated trough and the axis of rotation aligned with the tip of the acromion process. Weights were used to counterbalance the weight of the Biodex attachments.

Data Acquisition

Dynamometer analog signals (torque and position) were obtained directly from the dynamometer using a 12 bit A/D converter (Keithly Instruments, Inc., Taunton, Mass) and custom written software (C++). Data were sampled at 1 kHz and written to disk for off-line analysis.

Protocol

Each participant was tested at 3 separate occasions: day 1 (session 1), day 7 (session 2), and 6 weeks later (session 3). These time intervals were selected because baseline tests are commonly done one week apart and clinical trials often involve 6 weeks of intervention requiring both pre- and post-tests. Isokinetic concentric elbow flexion, elbow extension, and shoulder flexion of both the ipsilesional and contralesional arms were performed at 3 criterion angular speeds: 30º/s, 75º/s, and 120º/s. The order of testing (ipsilesional v/s contralesional arms) was randomly selected on day 1 and remained consistent across sessions and the order of speeds was slow to fast. Participants were asked to 'move the handle as hard and as fast as possible' for a total of 4 trials which included a practice trial and 3 actual trials. Each of the trials was a single, discrete trial of either flexion or extension. A rest period of 30 seconds was provided between trials. Verbal encouragement was given only during the practice trials.

Analysis

The analog torque and position signals were digitally low-pass filtered (20 Hz cutoff, zero-phase shift, low-pass 1st-order Butterworth filter) using MATLAB (Version 6.5.0, Natick, Mass). Speed was calculated by taking the derivative of the filtered position signal. The calculated speed signal was then digitally low-pass filtered at 20 Hz. Data for each of the isokinetic conditions were examined over the middle 30º of the subject's active range of motion. Actual ranges of motion for each movement and criterion speed are presented in Table 2. For each of the 3 trials, the mean torque and mean speed during this 30º window were calculated. Data from the 3 trials were then averaged to determine the torque and actual speed reported for each of the 3 criterion angular speeds. Although criterion speeds were preselected as 30°/s, 75°/s, and 120°/s, many participants were unable to reach these speeds and their actual speed was generally lower than the criterion speeds especially for the fast criterion. Therefore, power was calculated to account for differences in torque due to variations in actual speed across participants. Power was defined as the product of torque and actual angular speed of movement.

Table 2. Mean Position (start position-end position) ± SE of Actual Ranges of Motion Analyzed

		Contralesional	Ipsilesional
Elbow Flexion at	30°/s	63.5 – 33.5 ± 1.3	36.0 – 66.0 ±1.4
	75°/s	13.7 – 43.7 ± 1.1	9.0 – 39.0 ± 1.1
	120°/s	5.6 – 35.6 ± 1.1	5.0- 29.4 ± 0.9
Elbow Extension at	30°/s	57.2 – 27.2 ± 1.5	33.5 – 63.5 ±1.3
	75°/s	40.7 – 10.7 ± 1.4	38.9 – 8.9 ±1.1
	120°/s	27.9 – 5.0 ± 1.1	24.5 – 5.5 ± 0.9
Shoulder Flexion at	30°/s	16.6 – 46.6 ± 1.7	23.3 – 53.3 ±1.4
	75°/s	5.1 – 35.1 ± 1.2	5.4 – 35.4 ±1.1
	120°/s	5.3 – 28.5 ± 1.0	5.4 – 25.4 ±1.0

Note: For elbow, 0° = full extension with positive value indicating increasing flexion; shoulder, 0° = neutral position (arm by side of body) with positive values indicating increasing flexion. The active range of motion decreased systematically as speed increased. Torque and speed were averaged over the middle 30° of the active range of motion to obtain a representative measure of functional performance in the criterion movements.

For each of the 3 variables (torque, actual speed, and power), relative reliability was established through the calculation of ICC for 2-way mixed effect model single measure reliability (ie, $ICC_{(3,1)}$) with SPSS, version 11.0. If BMS represents the variability between subjects, EMS the residual mean square and k the number of trials, then

$$ICC_{(3,1)} = \frac{BMS - EMS}{BMS + (k - 1)\, EMS}$$

To determine the absolute reliability of the measures, we calculated the measurement error (SEM) as the square root of the within subjects variability obtained from the ANOVA table used to calculate the ICC. The measurement error was expressed as SEM% ([SEM/mean] x 100). In addition, we established the smallest magnitude of change in torque and power that would constitute a clinically important change by quantifying the 'smallest real difference' (SRD= 1.96 √ [2 x SEM]).[24] All analyses were performed for sessions 1 v/s 2, and sessions 2 v/s 3.

RESULTS

Torque, Speed, and Power

All participants were able to perform elbow flexion (EF) and shoulder flexion (SF) but 3 participants were unable to perform elbow extension (EE) on the contralesional side. For all 3 actions tested, torque in the ipsilesional limb (mean across 3 sessions and 3 criterion speeds = 24.9 Nm EF, 22.7 Nm EE, 24.8 Nm SF) was at least twice as large as in the contralesional side (mean = 10.3 Nm EF, 11.1 Nm EE, 11.5 Nm SF). These data are illustrated in Figure 2. No systematic changes in magnitude were observed across sessions for any of the three actions.

In this group of participants, there was no clear evidence of a systematic pattern of torque deficits across the 3 actions tested. That is, the torque in the contralesional relative to the ipsilesional limb was not noticeably weaker in one particular action compared to another. However, there was a systematic increase in torque deficits with increasing speed for all 3 actions (Figure 2). For example, mean elbow flexion torque in the contralesional limb was 47%, 41%, and 35% of that in the ipsilesional limb at criterion speeds of 30º/s, 75º/s, and 120º/s, respectively. Similarly, relative to the ipsilesional side, contralesional elbow extension torque was 60%, 46%, and 38% and shoulder flexion torque was 50%, 47%, and 43% at criterion speeds of 30°/s, 75°/s, and 120º/s, respectively.

As anticipated, several participants were unable to generate limb movement at the selected criterion angular

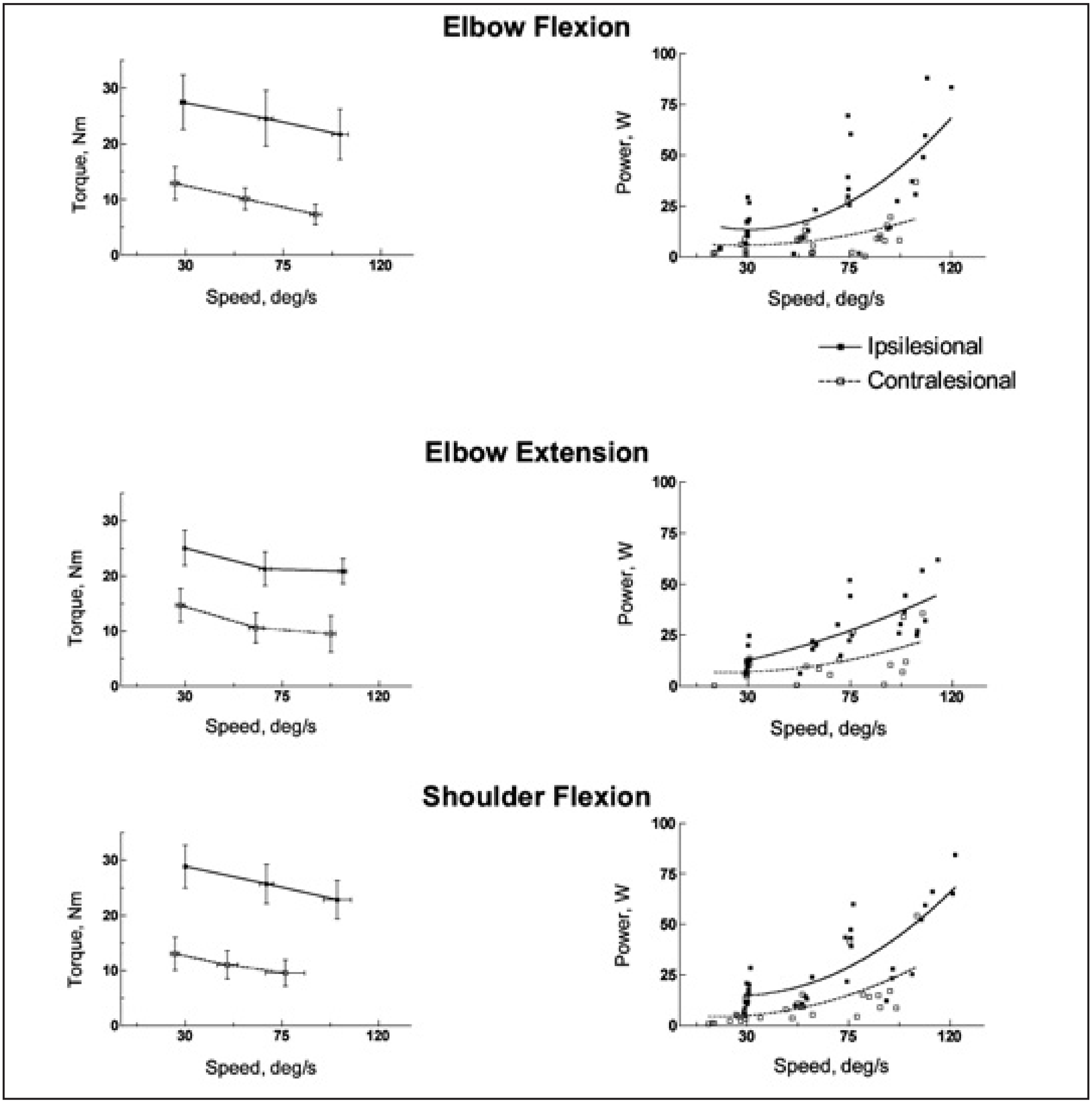

Figure 2. Torque (left column) and power (right column) of the contralesional (dashed lines) and ipsilesional (solid lines) elbow flexion, elbow extension, and shoulder flexion as a function of actual speed. Plots in left column correspond to mean and standard error of the mean (error bars) of torque and actual speed values from Session 1 (Day 1). Plots in right column are scatterplots of individual participant data with regression lines of power v/s actual speed from Session 1 (Day 1). Note that speed data do not extend to 120°/s as the data represent actual speed rather than criterion speed.

speeds. For elbow flexion, 20%, 68%, and 90% of cases did not reach criterion speeds (± 5°/s) of 30°/s, 75°/s, and 120°/s, respectively, across sessions. For elbow extension, the percentage of cases that did not reach the criterion speeds of 30°/s, 75°/s, and 120°/s was 7%, 53%, and 96% and for shoulder flexion 13%, 65%, 92%, respectively.

Figure 2 illustrates the relationship between power and speed of movement for all 3 actions from Session 1. Similar to the torque deficit pattern described above, the disparity in power between limbs increased as speed increased. The mean power of the contralesional arm relative to the ipsilesional arm was 41%, 34%, and 30% for elbow flexion, 59%, 44%, and 36% for elbow extension, and 46%, 38%, and 35% for shoulder flexion at criterion speeds of 30º/s, 75º/s, and 120º/s, respectively.

Reliability Analysis

According to Fleiss,[25] ICCs in the range of 0.5-0.6 are fair, 0.6-0.7 good, and above 0.75 excellent. Using these criteria, relative reliability was excellent for torque and power (0.82-0.98) and good to excellent for speed (0.63-0.99) (Table 3). The ICC values were high and of comparable ranges for both the ipsilesional and contralesional limbs. These relationships were consistent across sessions.

Measurement error (SEM%) ranged between 7% to 32% for torque, 0% to 15% for speed, and 9% to 34% for power across sessions, for both limbs, and all speeds (Table 4). No systematic pattern was observed in the magnitude of error across sessions or movement speeds. However, SEM% was somewhat higher on the contralesional limb when compared to the ipsilesional limb.

In addition to establishing reliability, we used SRD scores to determine the smallest magnitude of change necessary to detect a real change in upper limb torque and power. SRD scores ranged between 4-11Nm for torque and 3-24W for power (Table 5). No systematic pattern in the magnitude of SRD was noted across sessions, limb sides (contralesional v/s ipsilesional), or movement speeds for torque. However, for power, SRD scores generally increased with increasing speed.

DISCUSSION

The results of the present study show that dynamic shoulder flexion, elbow flexion, and elbow extension can be assessed reliably in persons with chronic post-stroke hemiparesis. We selected elbow flexion, elbow extension, and shoulder flexion actions to represent upper limb func-

Table 3. ICC Values Across the 3 sessions for Torque, Actual Speed, and Power (N = 10)

	Torque		Actual Speed		Power	
Action	Sessions 1-2	Sessions 2-3	Sessions 1-2	Sessions 2-3	Sessions 1-2	Sessions 2-3
Ipsilesional						
EF 30°/s	0.97	0.98	0.99	0.91*	0.97	0.98
(95% CI)	(0.90-0.99)	(0.93-0.99)	(0.99-0.99)	(0.66-0.98)	(0.90-0.99)	(0.93-0.99)
75°/s	0.93	0.97	0.92	0.96	0.94	0.97
(95% CI)	(0.74-0.98)	(0.88-0.99)	(0.71-0.98)	0.86-0.99)	(0.77-0.98)	(0.90-0.99)
120°/s	0.96	0.99	0.81	0.94	0.96	0.98
(95% CI)	(0.87-0.99)	(0.96-0.99)	(0.40-0.95)	(0.76-0.98)	(0.84-0.99)	(0.94-0.99)
EE 30°/s	0.83	0.82	0.86	0.88	0.83	0.82
(95% CI)	(0.47-0.96)	(0.43-0.95)	(0.54-0.96)	(0.59-0.97)	(0.46-0.96)	(0.43-0.95)
75°/s	0.89	0.89	0.75	0.99	0.83	0.91
(95% CI)	(0.62-0.97)	(0.63-0.97)	(0.27-0.93)	(0.97-0.99)	(0.44-0.95)	0.69-0.98)
120°/s*	0.88	0.90	0.89	0.97	0.88	0.92
(95% CI)	(0.55-0.97)	(0.62-0.98)	(0.59-0.97)	(0.88-0.99)	(0.57-0.97)	(0.69-0.98)
SF 30°/s	0.96	0.92	0.99	0.63	0.96	0.93
(95% CI)	(0.85-0.99)	(0.72-0.98)	(0.96-0.99)	0.04-0.89)	(0.86-0.99)	(0.73-0.98)
75°/s	0.90	0.91	0.92	0.92	0.94	0.93
(95% CI)	(0.65-0.97)	(0.68-0.98)	(0.72-0.98)	(0.72-0.98)	(0.77-0.98)	(0.73-0.98)
120°/s	0.83	0.87	0.97	0.73	0.87	0.88
(95% CI)	(0.46-0.96)	(0.55-0.96)	(0.89-0.99)	(0.23-0.93)	(0.57-0.97)	(0.60-0.97)
Contralesional						
EF 30°/s	0.90	0.93	0.64	0.84	0.84	0.92
(95% CI)	(0.65-0.97)	(0.73-0.98)	(0.05-0.89)	(0.47-0.96)	(0.47-0.96)	(0.71-0.98)
75°/s	0.90	0.94	0.92	0.82	0.89	0.95
(95% CI)	(0.64-0.97)	(0.78-0.98)	(0.70-0.98)	(0.42-0.95)	(0.61-0.97)	(0.80-0.99)
120°/s	0.92	0.93	0.82	0.72	0.92	0.93
(95% CI)	(0.72-0.98)	(0.75-0.98)	(0.43-0.95)	(0.21-0.92)	(0.71-0.98)	(0.75-0.98)
EE** 30°/s	0.97	0.89	0.99	0.99	0.98	0.90
(95% CI)	(0.85-0.99)	(0.49-0.98)	(0.99-0.99)	(0.99-0.99)	(0.87-0.99)	(0.52-0.98)
75°/s	0.94	0.86	0.94	0.98	0.92	0.86
(95% CI)	(0.68-0.99)	(0.40-0.97)	(0.67-0.99)	(0.90-0.99)	(0.60-0.99)	(0.38-0.97)
120°/s	0.85	0.84	0.94	0.92	0.83	0.83
(95% CI)	(0.26-0.98)	(0.33-0.97)	(0.66-0.99)	(0.61-0.99)	(0.21-0.97)	(0.29-0.97)
SF 30°/s*	0.92	0.95	0.79	0.79	0.92	0.95
(95% CI)	(0.70-0.98)	(0.81-0.99)	(0.32-0.95)	(0.30-0.95)	(0.69-0.98)	(0.80-0.99)
75°/s	0.92	0.90	0.95	0.90	0.94	0.93
(95% CI)	(0.71-0.98)	(0.65-0.97)	(0.80-0.99)	(0.66-0.98)	(0.78-0.98)	(0.75-0.98)
120°/s	0.87	0.93	0.96	0.96	0.88	0.97
(95% CI)	(0.57-0.97)	(0.75-0.98)	(0.83-0.99)	(0.84-0.99)	(0.59-0.97)	(0.89-0.99)

The three angular speeds describing each action are the criterion speeds at which participants were asked to generate torque

* N=9 for analysis of ipsilesional EE 120°/s and contralesional SF 30°/s due to missing data and N=9 for actual speed (sessions 2-3) of ipsilesional EF 30°/s due to an outlier

** N=7 for contralesional elbow extension analysis due to three participants' inability to generate torque in elbow extension

EF = Elbow Flexion; EE = Elbow Extension; SF = Shoulder Flexion; CI = confidence interval for ICC

Table 4. Measurement Error (SEM%) Across the 3 sessions for Torque, Actual Speed, and Power (N=10)

	Torque		Actual Speed		Power	
Action	Sessions 1-2	Sessions 2-3	Sessions 1-2	Sessions 2-3	Sessions 1-2	Sessions 2-3
Ipsilesional						
EF 30°/s	8.96	7.72	0.45	0.47*	9.56	9.22
75°/s	15.07	10.78	3.83	2.49	15.82	11.6
120°/s	11.27	7.06	4.62	2.57	13.79	9.85
EE 30°/s	15.44	14.99	0.61	0.56	16.03	15.44
75°/s	14.86	13.78	6.27	1.23	21.33	14.36
120°/s*	12.45	12.12	2.00	1.49	13.66	12.45
SF 30°/s	8.69	11.13	0.35	2.95	9.02	11.41
75°/s	13.49	12.51	5.23	5.16	14.55	14.53
120°/s	18.59	15.70	3.79	8.72	21.54	18.50
Contralesional						
EF 30°/s	20.55	18.78	15.23	9.89	33.00	25.42
75°/s	17.57	13.96	2.83	4.26	21.59	15.67
120°/s	19.01	16.04	3.59	7.08	20.87	17.35
EE** 30°/s	12.41	25.60	0.36	0.75	12.88	25.95
75°/s	15.74	30.32	3.97	1.95	19.66	32.55
120°/s	28.96	32.47	1.31	1.40	31.26	33.90
SF 30°/s*	19.14	18.84	10.86	11.62	22.68	23.21
75°/s	18.24	21.38	7.00	9.62	22.48	24.38
120°/s	23.85	15.62	7.54	7.00	31.87	14.13

The three angular speeds describing each action are the criterion speeds at which participants were asked to generate torque
* N=9 for analysis of ipsilesional EE 120°/s and contralesional SF 30°/s due to missing data and N=9 for actual speed (sessions 2-3) of ipsilesional EF 30°/s due to an outlier
** N=7 for contralesional elbow extension analysis due to three participants' inability to generate torque in elbow extension
EF = Elbow Flexion; EE = Elbow Extension; SF = Shoulder Flexion

Table 5. Smallest Real Difference (SRD) Across the 3 Sessions for Torque and Power (N=10)

	Torque (Nm)		Power (W)	
Action	Sessions 1-2	Sessions 2-3	Sessions 1-2	Sessions 2-3
Ipsilesional				
EF 30°/s	± 6.66	± 5.80	± 3.67	± 3.35*
75°/s	±10.23	± 7.55	± 13.29	± 10.01
120°/s	± 6.83	± 4.44	± 15.71	± 11.79
EE 30°/s	±10.56	± 10.27	± 5.71	± 5.52
75°/s	± 8.95	± 8.56	± 15.60	± 10.96
120°/s*	± 7.23	± 7.18	± 14.46	± 13.60
SF 30°/s	± 6.75	± 8.35	± 3.70	± 4.49
75°/s	± 9.28	± 8.44	± 12.18	± 11.87
120°/s	± 11.28	± 9.27	± 23.98	± 19.85
Contralesional				
EF 30°/s	± 7.04	± 6.62	± 5.04	± 4.01
75°/s	± 4.86	± 4.02	± 6.06	± 4.60
120°/s	± 3.97	± 3.58	± 7.15	± 6.37
EE** 30°/s	± 5.41	± 10.54	± 2.92	± 5.58
75°/s	± 4.79	± 8.38	± 6.95	± 10.54
120°/s	± 7.22	± 6.76	± 13.60	± 12.26
SF 30°/s*	± 7.01	± 7.42	± 3.94	± 4.41
75°/s	± 5.61	± 7.03	± 6.77	± 8.02
120°/s	± 6.11	± 4.04	± 12.05	± 5.33

The three angular speeds describing each action are the criterion speeds at which participants were asked to generate torque
* N=9 for analysis of ipsilesional EE 120°/s and contralesional SF 30°/s due to missing data and N=9 for actual speed (sessions 2-3) of ipsilesional EF 30°/s due to an outlier
** N=7 for contralesional elbow extension analysis due to three participants' inability to generate torque in elbow extension
EF = Elbow Flexion; EE = Elbow Extension; SF = Shoulder Flexion

tion because these movements are important in common daily functions. We also selected a wide range of movement speeds, as functional tasks often require the upper limb to perform at various speed conditions. In addition, we established reliability of these performance measures across 3 test sessions over a 7-week time interval.

Though other methods of strength testing may be more readily available at clinics (eg, manual muscle testing or isometric testing with hand-held dynamometers), there are several advantages of isokinetic testing over these simpler methods. The most important advantage of testing with dynamometry is that it provides an accurate indication of muscle strength over a range of movement speeds. It is known that the magnitude of torque decreases with increasing movement speed.[26] This phenomenon has also been shown in adults with post-stroke hemiparesis for both upper[20] and lower[27] limbs. In addition, speed may have different effects on the contralesional compared to the ipsilesional arm following stroke.[20] Most importantly, functional activities require that the arms generate torque at a range of movement speeds. For example, elbow extension speed during reaching tasks was found to be greater than 400°/s in healthy adults and about 210°/s in persons post-stroke.[28] Thus the criterion speeds used in this study to test muscle performance approach the range of speeds that should be within the functional capacity of these participants. Other obvious advantages of isokinetic testing over a simpler method of testing such as manual muscle testing are that it provides a quantitative, continuous measure and is more sensitive to differences in strength across individuals.

Isokinetic torque is commonly used as an outcome measure in lower limb studies, however, few have used isokinetic torque as a measure of upper-limb performance in persons with post-stroke hemiparesis.[20,29] In this study, we have demonstrated the feasibility of measuring isokinetic torque at the shoulder and elbow of the hemiparetic limb with highly reliable results. As expected, torque on the contralesional limb was consistently lower than on the ipsilesional limb, the former reaching only half the torque of the latter for both elbow (41% in flexion, 48% in extension) and shoulder (47% in flexion) joints. However, the distribution of weakness did not appear to follow any clear pattern across the 3 actions tested. These results agree with other studies that also failed to demonstrate a systematic distribution pattern of weakness following stroke.[2,16]

As previously demonstrated by others,[20,27] torque decreased with increasing speed in both contralesional and ipsilesional limbs. In addition, contralesional torque and power, when observed as a percentage of the values on the ipsilesional side, decreased with increasing speed for all 3 actions. Inconsistent with this observation, Bohannon[27] found that for knee extension torque, the relative decrease in torque with increasing speed was not different between the 2 sides. Our results, however, agree with Lum and colleagues'[20] findings that the decline in upper-limb torque as speed increases is greater in the contralesional than in the ipsilesional limb. Observations of the present study further support isokinetic resistance training at fast speeds as an approach for reversing speed-dependent movement deficits of the upper-limb as well as including various speed conditions when testing the effectiveness of intervention following stroke.

Most of our participants were unable to generate torque at the higher selected criterion speeds, especially on the contralesional side. Interestingly, with increased criterion speed, limb movements were faster, but still did not meet the preselected speed (Figure 2). Given the speed-dependent nature of torque production, this inability to reach criterion speeds brings into question the validity of between-subject comparisons of torque that may have been obtained at different actual speeds. Thus, power may be a more valid measure of dynamic muscle performance. It could provide a more meaningful representative measure when analyzing performance effects across groups or pre- and postintervention.

To our knowledge, this is the first study investigating the reliability of upper limb isokinetic performance in persons with post-stroke hemiparesis. Relative reliability as measured by ICC was high in all 3 actions for both limbs even at high movement speeds. While not formally assessed, it appears that hypertonia did not interfere with the consistency of muscle performance from session to session. Although a formal measure of hypertonia was not included in our protocol, the presence of increased muscle tone (ie, increased resistance to passive movement) was apparent (therapist's observations via manual test) in 8/10 participants. Other studies[10,13] have also suggested that torque reliability was not affected by muscle tone in the hemiparetic lower limb. For example, Tripp and Harris[13] reported excellent ICC values in the hemiparetic knee at speeds as high as 120°/s in spite of the presence of considerable increase in tone as measured by the Ashworth Scale.

The ICC values for upper limb torque found in this study are of comparable ranges to values found in other studies involving isokinetic strength of the hemiparetic lower limb. With the exception of Pohl et al's[12] knee flexion torque, all studies have reported high ICCs (0.76-0.99) for lower limb torque at movement speeds of 30°/s to 120°/s.[10-13] Only Hsu et al[11] included power in their analysis and found good ICCs (0.62-0.90) for the hemiparetic lower limb. No other study has addressed the reliability of movement speed. This circumstance is possibly due to methodological differences such as differences in dynamometer features (eg, the Kin-Com dynamometer does not allow movement in the isokinetic mode unless participants are capable of producing a threshold torque level through the full range of motion, thus subjects exhibiting velocity-dependent weakness would be unable to advance the dynamometer at higher criterion speeds[30]) or differences in data analysis methods (eg, data from participants that cannot reach criterion speeds are excluded from analysis).[14] Furthermore, it is possible that the inability to perform fast movements is more pronounced in the upper than in the lower limb following stroke.

As previously mentioned, in the present study we found that several participants were consistently unable to reach the preselected criterion speeds, including the slow speed of 30°/s. Therefore, we included 'actual speed' achieved in our reliability analysis. Whereas torque and power resulted in excellent reliability, ICC values for speed were somewhat lower. In general, ICC values tend to be lower when the variability between subjects is low.[23,25] Low intersubject variability is a likely reason for lower ICCs found for the speed variable in this study given that all participants attempted to perform at the same criterion speeds. Poorer reliability for the speed variable provides another rationale for the use of power as a reliable, representative measure of muscle performance.

In addition to relative reliability that determines the consistency of measures across sessions, it is important to establish the absolute reliability of a measure by quantifying the variability of repeated measurements within subjects. We used standard error of measurement as a percentage of the mean (SEM%) to describe the measurement noise caused by repeated measures within a subject. In spite of the inability of most participants to meet criterion speeds, SEM% for actual speed was fairly low (< 16%) indicating that the speed achieved was reproduced from session to session. The SEM% values were low to moderate (< 35%) for torque and power and generally higher for the contralesional limb. This is not surprising given the reduction in mean torque and power on the contralesional compared to the ipsilesional side. These results indicate that for the weaker contralesional muscle groups, a greater percentage of change in torque or power is necessary in order to demonstrate significant changes over time. However, as demonstrated by the SRDs, the absolute magnitude of torque or power needed to detect real change over time is similar between contralesional and ipsilesional limbs. For example, the same 8Nm torque change in elbow flexion would be sufficient to demonstrate a significant change over time for both the contralesional and ipsilesional limbs and yet it would correspond to a greater percentage of change for the weaker contralesional side.

Interestingly, we did not find that the experience or practice with the isokinetic testing during session 1 resulted in improved ICC, SEM%, or SRD values in subsequent sessions. The lack of a practice effect may be explained by consistent use of a familiarization trial prior to performance of the actual experimental trials. This observation indicates that a practice session is not necessary prior to upper limb isokinetic testing to produce reliable results.

CONCLUSION

This study established the test-retest reliability of dynamic shoulder flexion, elbow flexion, and elbow extension in persons with chronic post-stroke hemiparesis. Our results revealed that concentric isokinetic performance of shoulder flexion, elbow flexion, and elbow extension can be evaluated with highly reliable results without a practice session. As many individuals with post-stroke hemiparesis are unable to generate torque at preselected criterion speeds, power may be a more valid indicator of overall muscle performance in this population. Our results also emphasize the importance of isokinetic testing over a range of speeds when examining the relationships between muscle strength and functional tasks as well as when evaluating intervention effectiveness following stroke.

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