Short communication

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Assessment of isometric muscle strength and rate of torque development with hand-held dynamometry: Test-retest reliability and relationship with gait velocity after stroke

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Abstract

Isometric rate of torque development examines how quickly force can be exerted and may resemble everyday task demands more closely than isometric strength. Rate of torque development may provide further insight into the relationship between muscle function and gait following stroke. Aims of this study were to examine the test-retest reliability of hand-held dynamometry to measure isometric rate of torque development following stroke, to examine associations between strength and rate of torque development, and to compare the relationships of strength and rate of torque development to gait velocity. Sixty-three post-stroke adults participated (60 years, 34 male). Gait velocity was assessed using the fast-paced 10m walk test. Isometric strength and rate of torque development of seven lower-limb muscle groups were assessed with hand-held dynamometry. Intraclass correlation coefficients were calculated for reliability and Spearman's rho correlations were calculated for associations. Regression analyses using partial *F*-tests were used to compare strength and rate of torque development in their relationship with gait velocity. Good to excellent reliability was shown for strength and rate of torque development (0.82-0.97). Strong associations were found between strength and rate of torque development (0.71-0.94). Despite high correlations between strength and rate of torque development, rate of torque development failed to provide significant value to regression models that already contained strength. Assessment of isometric rate of torque development with hand-held dynamometry is reliable following stroke, however isometric strength demonstrated greater relationships with gait velocity. Further research should examine the relationship between dynamic measures of muscle strength/torque and gait after stroke.

Keywords: rate of force development; muscle power; neurological rehabilitation; weakness; stroke

1. Introduction

Evidence suggests that muscle weakness is a key impairment limiting gait following stroke (Bohannon, 1989). Previous studies have examined the associations between maximal strength and gait velocity after stroke (Mentiplay et al., 2015a), however, there is limited evidence that strength training improves gait in neurological rehabilitation (Salter et al., 2016; Williams et al., 2014). Rate of torque development (RTD) is defined as the change in torque over change in time during an isometric contraction (Maffiuletti et al., 2016) and indicates how quickly muscles generate force. Compared with traditional measures of strength, RTD may provide greater insight into the relationship between weakness and gait velocity. Research in other clinical populations, such as those with cerebral palsy (Moreau et al., 2012), anterior cruciate ligament reconstruction (Pua et al., 2017) and knee osteoarthritis (Winters and Rudolph, 2014), has shown isometric RTD to provide larger associations compared to isometric strength with various measures of physical function including gait. One previous study in stroke found isometric RTD demonstrated a superior relationship with gait velocity compared to strength (Pohl et al., 2002). This study by Pohl et al. (2002) only assessed the knee extensors which are not prime movers during gait (Olney et al., 1991). The ankle plantar flexors are more affected compared to proximal muscle groups post-stroke (Adams et al., 1990), and provide the majority of power generation during gait (Winter, 1983). It is possible that the isometric RTD of other muscle groups, such as the plantar flexors, may demonstrate greater relationships with gait velocity compared to the knee extensors.

To aid clinical implementation, recent iterations of hand-held dynamometry (HHD) have allowed raw data to be exported and isometric RTD processed post-assessment. Good to excellent reliability and validity has been shown for isometric RTD measures assessed with HHD in a healthy cohort (Mentiplay et al., 2015b). Additionally, isometric strength assessed with HHD in neurological populations has shown excellent reliability (Bohannon, 1986; Riddle et al., 1989). However, the properties of HHD for assessment of RTD are currently unknown following stroke. Therefore, the aim of the current study was to firstly examine the test-retest reliability of isometric strength and RTD measures using HHD, secondly to examine the associations between measures of isometric strength and RTD, and thirdly to compare the relationships of muscle strength and RTD with gait velocity after stroke. Based on similar previous research in clinical cohorts, it was hypothesised that RTD would demonstrate greater relationships with gait velocity compared to muscle strength.

2. Methods

2.1 Participants

A convenience sample of adults 21 years or older were recruited from two major hospitals in Australia and Singapore. Inclusion criteria were: (1) confirmed stroke >3 months prior; and (2) ability to walk >10m without gait aids or orthoses. Exclusion criteria were: (1) cerebellar stroke; (2) cognitive impairment; and (3) other diagnosed comorbidities that would impact physical participation. Ethics approval was obtained from the hospitals and all participants provided written informed consent. Testing was performed at the hospital where participants were recruited. Power calculations were undertaken prior to the study (de Vet et al., 2011; Portney and Watkins, 2009), which revealed 62 participants were required to examine the relationships between strength, RTD and gait velocity, while 25 participants were required for reliability analysis.

2.2 Gait velocity

Measurement of gait velocity was performed first and involved two trials of the 10m walk test performed as fast as possible, barefoot and without gait aids or orthoses. Participants walked a total of 14m, with 2m either side used to avoid timing of acceleration or deceleration. The time taken to walk the central 10m was recorded with a stopwatch, with the same assessor performing all assessments of gait velocity. The fastest recorded velocity of the two trials was used for analysis.

2.3 Isometric strength and RTD

Lower-limb isometric strength and RTD were assessed using a Lafayette Manual Muscle Testing System Model-01165 (Lafayette Instrument Company, Lafayette IN, USA) with additional foam padding (12mm EVA foam) to protect the participants from potential discomfort. Seven lower-limb muscle groups were assessed according to a previously described protocol that has been shown to be reliable and valid for strength and RFD assessment in a healthy cohort (Mentiplay et al., 2015b). The muscle groups were tested in the following order: hip flexors, knee extensors and knee flexors (seated); ankle plantar flexors, ankle dorsiflexors and hip abductors (supine); and hip extensors (prone). This protocol was chosen to minimise the position changes for participants.

Participants were asked to perform maximal isometric voluntary contractions by pushing/pulling as hard and as fast as they could against the HHD, which was held stationary by the assessor ('make' test). One practice trial was provided on the non-paretic limb followed by two recorded trials of the non-paretic and paretic limb. One assessor performed all assessments, who has demonstrated acceptable reliability and validity previously in a healthy population (Mentiplay et al., 2015b). A sub-group of participants returned for a second assessment to examine the test-retest reliability of isometric strength and RTD.

Raw force data (in Newtons) were filtered and resampled according to a previous protocol (Mentiplay et al., 2015b), converted to torque by multiplying by the lever arm (measured as the distance between the HHD and the joint centre being assessed using a tape measure) and normalised to body mass. The RTD was calculated by scanning successive time intervals of

200ms across the torque trace to determine peak RTD across the trial; this method has shown to possess the strongest reliability of various RTD methods (Mentiplay et al., 2015b). Other methods have used the onset of contraction to calculate RTD, although large variety exists in the thresholds used to define the onset of contraction (Maffiuletti et al., 2016). It was decided not to use the onset of contraction method as previous work has commented on the arbitrary nature of defining the onset of contraction (Pua et al., 2008), and the HHD had an in-built threshold to start recording (set at 1N for this study). Across the two trials, the highest torque reading was used for isometric strength (Nm/kg) and the highest peak RTD (Nm/s/kg) was used for analysis. A score of zero was recorded if participants were unable to generate any force against the dynamometer.

2.4 Statistical analysis

Descriptive statistics were used for participant characteristics. Test-retest reliability was assessed using a two-way random effects model intraclass correlation coefficient ($ICC_{2,k}$) with 95% confidence intervals. Spearman's rho correlations were used to determine associations and examine any redundancies between the two muscle function measures (strength and RTD) for each muscle group (i.e. if strong correlations exist between strength and RTD, potential redundancy exists). Linear regression models were used to evaluate the relationships of isometric strength and RTD measures with gait velocity, adjusting for four pre-specified covariates: age, gender, time since stroke, and country recruited. Partial *F*-tests (Harrell Jr., 2015) were used to determine whether isometric RTD added incremental predictive value to a linear regression model that included both the strength measures and covariates, and vice versa.

ICC values were categorised as excellent (≥ 0.90), good (0.75-0.89), moderate (0.50-0.74), or poor (< 0.50) (Portney and Watkins, 2009) and Spearman's rho values as very strong (≥

0.80), strong (0.60-0.79), moderate (0.40-0.59), weak (0.20-0.39), or very weak (< 0.20) (Evans, 1996). Analyses were performed using SPSS V23 (IBM Corp., Armonk, NY USA).

3. Results

Characteristics of the 63 recruited participants are provided in Table 1.

3.1 Test-retest reliability of HHD

Twenty-eight participants returned for the second testing session. Results demonstrated good to excellent test-retest reliability for isometric strength (ICCs = 0.82-0.97) and RTD (ICCs = 0.88-0.97) across all muscle groups and limbs (Table 2).

3.2 Associations between strength and RTD

Strong to very strong correlations were found between measures of isometric strength and RTD for the paretic (rho = 0.80-0.94) and non-paretic (rho = 0.71-0.85) limbs.

3.3 Comparison between strength and RTD relationships with gait velocity

Across all muscle groups, RTD did not provide significant additional value over isometric strength when predicting gait velocity, adjusting for covariates (Table 3). In contrast, all muscle groups except the knee extensors demonstrated superior relationships between isometric strength and gait velocity than RTD. It should be noted that both strength and RTD provided significant value over a covariates-only model (data not shown).

4. Discussion

Assessment of isometric strength and RTD using HHD showed good to excellent test-retest reliability. Strong to very strong correlations were shown between isometric strength and RTD, indicating potential redundancy between measures (i.e. strength and RTD predicted each other easily). Both measures of strength and RTD provided significant predictive value to gait velocity over a covariates-only model. However, strength had significantly greater relationships with gait velocity compared to RTD. Contrary to our hypothesis, these results indicate that muscle strength explains a significantly higher amount of the variance in gait velocity following stroke compared with RTD.

These findings are in contrast to previous research which showed that isometric RTD had a superior relationship with gait velocity compared with strength after stroke; however, the previous research only examined the knee extensors and participants were allowed the use of gait aids, which may have impacted their results (Pohl et al., 2002). The regression model in the previous study only explained 12% of the variance in gait velocity (Pohl et al., 2002), compared with over 50% in the current study. This may be because our study assessed the muscles known to contribute more to forward progression during gait than the knee extensors, such as the ankle plantar flexors and hip flexors (Winter, 1991). Another previous study examined isometric knee extensor strength, as well as isokinetic power and velocity (measures of quick muscle contractions – similar to RTD although during isokinetic contractions), after stroke (Bohannon, 1992). This previous study found similar correlations to gait velocity for each measure of isometric strength and isokinetic power and velocity; however, the previous study also only assessed the knee extensors (Bohannon, 1992). Whilst our study did not show isometric RTD to have a greater relationship with gait velocity compared to strength, future research may examine measures of quick muscle contractions (such as RTD) assessed during dynamic contractions in those muscles important for forward progression (e.g. ankle plantar flexors).

The results of this study provide evidence that the assessment of isometric strength and RTD using HHD is reliable after stroke. Clinicians, who may already be using HHD for strength assessment, can also use HHD to provide a measure of rapid force production (i.e. RTD). Although RTD failed to provide additional value in the relationship with gait velocity over isometric strength, RTD is still a clinically useful measure that may be related to functional activities.

The use of a stopwatch for gait velocity assessment may be seen as a limitation; however, this method is commonly used in research and clinical practice and has shown strong validity compared to three-dimensional gait analysis (Clark et al., 2011). The use of HHD for assessment of RTD may also be a limitation. The HHD used may have had an insufficient sampling rate to adequately detect rapid changes in force. However, our previous validation study in a healthy cohort showed strong validity for HHD to assess isometric RTD compared with a criterion-reference laboratory-based dynamometer (Mentiplay et al., 2015b). The HHD also had foam attached to increase participant comfort, with the same piece of foam remaining for the entire study, which may have impacted our strength and RTD measures differently as the study progressed. While we did not mechanically test the foam repeatedly to ensure no change in its deformity patterns, we are confident that this was not a major factor given the total usage of the system was low and restricted to this study, and no visible degradation was apparent during the study. The muscle groups were also tested in differing positions with respect to gravity (e.g. hip flexion against gravity, knee extensors/flexors in gravity lessened positions). This may be a limitation especially in a population with weakness, however the protocol was chosen to reduce the position changes for participants and all strength and RTD scores were normalised to body mass. Additionally, RTD was assessed during an isometric contraction (muscle length does not change) that does not incorporate the rapid changes in joint position seen during gait. Assessment of dynamic muscle contractions that replicate the muscle function during walking (i.e. submaximal, quick contractions) may have stronger links with gait velocity after stroke.

In conclusion, assessment of isometric strength and RTD using HHD is reliable after stroke. Measures of isometric strength demonstrated superior relationships with gait velocity compared with RTD. Future work in neurological rehabilitation should consider dynamic assessments of muscle performance which replicate muscle function during walking.

Conflict of interest:

The authors declare that they have no conflict of interest.

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Table 1. Participant characteristics.

	Participants (n = 63)	
Age (years) mean (SD), range	60 (13), 31-86	
Gender (male) *n (%)*	34 (54%)	
Height (cm) mean (SD), range	164 (10), 145-184	
Mass (kg) mean (SD), range	67 (14), 35-110	
Time since stroke (months) mean (SD), range	39 (51), 3-262	
Paretic side (left) *n (%)*	33 (52%)	
Fast gait velocity (m/s) mean (SD), range	1.07 (0.47), 0.17-1.87	
	Paretic side	***Non-paretic side***
Isometric strength (Nm/kg) mean (SD)		
Ankle dorsiflexors	0.13 ± 0.09	0.23 ± 0.07
Ankle plantar flexors	0.22 ± 0.12	0.36 ± 0.12
Hip abductors	0.75 ± 0.35	0.97 ± 0.33
Hip extensors*	0.83 ± 0.38	1.09 ± 0.40
Hip flexors	0.59 ± 0.24	0.75 ± 0.24
Knee extensors	1.00 ± 0.34	1.22 ± 0.32
Knee flexors	0.49 ± 0.28	0.78 ± 0.24
Isometric RTD (Nm/s/kg) mean (SD)		
Ankle dorsiflexors	0.17 ± 0.15	0.34 ± 0.16
Ankle plantar flexors	0.36 ± 0.24	0.57 ± 0.26
Hip abductors	1.12 ± 0.71	1.52 ± 0.83
Hip extensors*	1.33 ± 0.78	1.92 ± 1.07
Hip flexors	1.07 ± 0.58	1.36 ± 0.58
Knee extensors	1.57 ± 0.82	1.88 ± 0.80
Knee flexors	0.74 ± 0.55	1.23 ± 0.58

Note: 22 participants recruited from Australia and 41 from Singapore. No significant differences were found ($P > 0.05$) between Australian and Singaporean cohorts for participant characteristics or variables of gait velocity and paretic side isometric strength or RTD (data not shown – assessed with the Mann-Whitney U test for continuous variables and the Chi-Squared test for categorical variables). RTD = rate of torque development; * = hip extensors only measured in 50/63 participants due to discomfort when lying prone. Isometric strength and RTD data only presented for the first testing session.

Table 2. Test-retest reliability of hand-held dynamometry measures of isometric strength and rate of torque development (n = 28).

	Paretic side		**Non-paretic side**	
	Strength	**RTD**	**Strength**	**RTD**
Ankle dorsiflexors	0.95 (0.89, 0.98)	0.92 (0.83, 0.96)	0.82 (0.61, 0.92)	0.89 (0.77, 0.95)
Ankle plantar flexors	0.97 (0.93, 0.99)	0.97 (0.94, 0.99)	0.92 (0.82, 0.96)	0.95 (0.88, 0.98)
Hip abductors	0.95 (0.88, 0.98)	0.89 (0.75, 0.95)	0.91 (0.81, 0.96)	0.88 (0.74, 0.94)
Hip extensors*	0.94 (0.87, 0.98)	0.93 (0.84, 0.97)	0.93 (0.83, 0.97)	0.94 (0.86, 0.98)
Hip flexors	0.96 (0.91, 0.98)	0.91 (0.81, 0.96)	0.95 (0.89, 0.98)	0.92 (0.82, 0.96)
Knee extensors	0.93 (0.84, 0.97)	0.94 (0.86, 0.97)	0.94 (0.88, 0.97)	0.90 (0.77, 0.95)
Knee flexors	0.95 (0.90, 0.98)	0.95 (0.88, 0.98)	0.91 (0.80, 0.96)	0.88 (0.74, 0.94)

Note: values are intraclass correlation coefficients with 95% confidence intervals presented in parentheses. The 28 participants were evenly recruited from Australia (n = 14) and Singapore (n = 14). * = hip extensors only measured in 23/28 participants due to discomfort when lying prone. Participants returned for their second testing session on average 16 ± 16 days later (range of 2 to 69 days), with many participants providing consent for the second session only if they had other medical appointments on the same day. RTD = rate of torque development.

Table 3. Comparison between isometric strength and rate of torque development of the paretic side in the relationship with gait velocity following stroke.

		Fast gait velocity	
	Total R^2	**Reduction in R^2**	***P*-value**
Ankle dorsiflexors	0.457		
Remove Strength		0.048	**0.03***
Remove RTD		0.000	0.78
Ankle plantar flexors	0.503		
Remove Strength		0.063	**0.01***
Remove RTD		0.000	0.98
Hip abductors	0.432		
Remove Strength		0.059	**0.02***
Remove RTD		0.012	0.28
Hip extensors	0.367		
Remove Strength		0.069	**0.04***
Remove RTD		0.010	0.41
Hip flexors	0.504		
Remove Strength		0.054	**0.02***
Remove RTD		0.005	0.48
Knee extensors	0.346		
Remove Strength		0.031	0.11
Remove RTD		0.016	0.25
Knee flexors	0.496		
Remove Strength		0.065	**0.01***
Remove RTD		0.002	0.71

Note: Total R^2 column reflects a total linear regression model containing covariates (age, gender, time since stroke (log transformed) and country recruited) and measures of both strength and RTD for that particular muscle group, with fast gait velocity as the dependent variable. The *P*-value is from a partial *F*-test evaluating the additional value of strength over RTD in the model, adjusting for covariates, and vice versa. For example, in the model involving ankle plantar flexors, the strength measure provided additional value over the RTD measure, as indicated by the significant *P*-value when strength was removed from the total model (0.01). In contrast, the RFD measure did not provide additional value over the strength measure, as indicated by the non-significant *P*-value when RTD was removed from the total model (0.98). * = indicates significant *P*-value when the measure was removed from the total model. The non-paretic side is not reported as no muscle group of the non-paretic side had a significant relationship with gait velocity (data not shown). RTD = rate of torque development.