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Short communication

Evaluation of measurements of propulsion used to reflect changes in walking speed in individuals poststroke

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ABSTRACT

Recent rehabilitation approaches for individuals poststroke have focused on improving walking speed because it is a reliable measurement that is associated with quality of life. Previous studies have demonstrated that propulsion, the force used to propel the body forward, determines walking speed. However, there are several different ways of measuring propulsion and no studies have identified which measurement best reflects differences in walking speed. The primary purposes of this study were to determine for individuals poststroke, which measurement of propulsion (1) is most closely related to their self-selected walking speeds and (2) best reflects changes in walking speed within a session. Participants ($N=43$) with chronic poststroke hemiparesis walked at their self-selected and maximal walking speeds on a treadmill. Propulsive impulse, peak propulsive force, and mean propulsive value (propulsive impulse divided by duration) were analyzed. In addition, each participant's cadence was calculated. Pearson correlation coefficients were used to determine the relationships between different measurements of propulsion versus walking speed as well as changes in propulsion versus changes in walking speed. Stepwise linear regression was used to determine which measurement of propulsion best predicted walking speed and changes in walking speed. The results showed that all 3 measurements of propulsion were correlated to walking speed, with peak propulsive force showed the strongest correlation. Similarly, when participants increased their walking speeds, changes in peak propulsive forces showed the strongest correlation to changes in walking speed. In addition, multiplying each measurement by cadence improved the correlations. The present study suggests that measuring peak propulsive force and cadence may be most appropriate of the variables studied to characterize propulsion in individuals poststroke.

1. Background

Stroke is the leading cause of long term disability in the U.S (Go et al., 2014). Slow walking speed is a commonly observed functional deficit in individuals poststroke (Dickstein, 2008; Schmid et al., 2007). Because walking speed is associated with independence and quality of life (Dobkin et al., 2010; Perry et al., 1995), recent rehabilitation studies used walking speed as a primary outcome measure (Dobkin et al., 2010). Propulsive force is correlated to walking speed (Andriacchi et al., 1977) and increases with increased walking speed in individuals poststroke (Hsiao et al., 2015). Thus, recent poststroke rehabilitations approaches have emphasized the importance of measuring and targeting propulsion (Awad et al., 2014; Phadke, 2012).

Propulsion, defined as the force used to propel the body forward, was measured in several different ways in previous studies. In particular, propulsive impulse, defined as the time integral of the anterior ground reaction force (AGRF), has been commonly used to characterize propulsion in recent studies for individuals poststroke (Beaman et al., 2010; Bowden et al., 2006; Kesar et al., 2014; Sousa et al., 2013; Turns et al., 2007). Propulsive impulse accounts for both propulsive force and the length of propulsive duration. Based on the impulse-momentum principle, impulse applied to a constant mass (body mass) would induce change in velocity. Thus, propulsive impulse may be associated with walking

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Abbreviations: AGRF, Anterior ground reaction force

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Table 1
Participants' inclusion/exclusion criteria.

Inclusion criteria	Exclusion criteria
A single cortical or subcortical stroke	Had a history of multiple strokes
A poststroke duration of at least 6 months	Cerebellar stroke
The ability to ambulate without the assistance of another individual	Lower extremity joint replacement
Sufficient cognitive function to follow instruction and communicate with the investigators	Bone or joint problems that limited their ability to walk
The ability to walk for 6 min without orthotic support	A resting heart rate outside of the range of 40–100 beats per minute
Sufficient passive dorsiflexion range of motion to position the ankle in a Neutral position with the knee extended	A resting blood pressure outside of the range of 90/60 to 170/90 mm Hg
Sufficient passive hip extension to extend the hip 10°	Neglect
	Hemianopia
	Unexplained dizziness during the past 6 months
	Chest pain or shortness of breath without exertion

speed. Peak propulsive force is another measurement that has been used to study forward propulsion during walking (Andriacchi et al., 1977; Campanini and Merlo, 2009; Franz et al., 2014; Goble et al., 2003; Hanley and Bissas, 2014; Kesar et al., 2011; Nilsson and Thorstensson, 1989; Sacco et al., 2010; Simmonds et al., 2012) and running (Moore et al., 2012). Improvements in peak propulsive force was correlated to long-term walking ability in individuals poststroke (Awad et al., 2014a). Different from propulsive impulse, peak propulsive force does not account for propulsive duration and only captures the maximal force generated during the propulsive phase. Another way to characterize propulsion is “mean propulsive value”, defined as the propulsive impulse divided by its time duration (Campanini and Merlo, 2009). Mean propulsive value therefore represents the average amount of propulsive force generated per step during the propulsive phase of gait. Because force is the product of mass and acceleration, it is expected that increasing propulsive force applied to the body center of mass would increase forward acceleration.

Despite the increasing evidence supporting the utility of measurements of propulsion, no studies have identified which measurement of propulsion is most closely related to individuals' walking speeds for persons with stroke. Campanini and colleagues reported that both peak propulsive force and mean propulsive value were similarly correlated with height-normalized walking speed in individuals poststroke. However, propulsive impulse was not reported in their study. In addition, if measurement of propulsion is responsible for walking speed, it is conceivable that changes in propulsion will be related to changes in walking speed. However, to date, the ability of each of these measurements of propulsion to reflect changes in walking speed in individuals poststroke has not been compared. The primary purposes of this study were to determine for individuals poststroke, which measurement of propulsion (1) is most closely related to their self-selected walking speeds and (2) best reflects changes in walking speed.

In the present study, we examined the relationships between walking speed and different measurements of propulsion in individuals poststroke: propulsive impulse, peak propulsive force, and mean propulsive value. In addition, because calculating propulsion per step does not account for the number of steps, we multiplied each measurement by cadence to quantify propulsion generated per second and tested whether accounting for cadence could enhance the sensitivity of measurements of propulsion to walking speed in individuals poststroke.

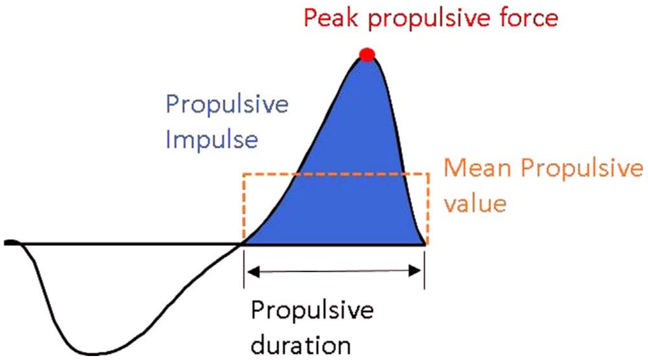

Fig. 1. Illustration for measurements of propulsion. Peak propulsive force was defined as the maximal anterior ground reaction force (AGRF) normalized to body weight. Propulsive impulse was the force-time integral of the AGRF normalized to body weight. Mean propulsive value was calculated by dividing the propulsive impulse by its time duration.

2. Methods

2.1. Participants

A total of 43 participants (age, 58.3 ± 11.8 years; time since stroke, 4.5 ± 6.5 years; 17 female; 16 right hemiparetic; self-selected walking speed, 0.7 ± 0.3 m/s) with poststroke lower extremity hemiparesis were included in this study (see Table 1 for inclusion/exclusion criteria). This study was approved by the Institutional Review Board of the University of Delaware and all participants provided written informed consent to participate in this study.

2.2. Gait evaluation

Kinetic and kinematic data were collected via an 8-camera (120 Hz sampling rate) motion analysis system (Motion Analysis Corp., Santa Rosa, CA, USA) as participants walked at their self-selected and fast speeds on a split-belt treadmill (Bertec Corp., Columbus, OH, USA) instrumented with 2 independent 6 degree of freedom force plates capturing at 1080 Hz. Self-selected walking speed was defined as the participant's comfortable over ground walking speed during a 10-meter walk test (Plummer et al., 2015) and fast walking speed was the fastest speed that participants could maintain for at least 4 minutes of continuous walking on the treadmill. Previous work has described in detail the gait analysis setup (Awad et al., 2014b; Kesar et al., 2014; Reisman et al., 2013). Participants wore an overhead support harness with no body weight support and used a handrail if needed for safety. Kinematic and kinetic data were filtered using a bi-directional Butterworth low-pass filter at 6 and 30 Hz, respectively. Changes during speed modulation were calculated as the differences between measurements at self-selected and fast walking speed. Peak propulsive force was defined as the maximal anterior ground reaction force (AGRF) normalized to body weight (see Fig. 1). Propulsive impulse was the force-time integral of the anterior phase of the AGRF normalized to body weight. Mean propulsive value was calculated by dividing the propulsive impulse by its time duration. Cadence was calculated by the number of steps divided by the length of the trial duration. All data were averaged across strides with 30 seconds trial duration for a given speed.

2.3. Statistical analysis

A sample size of 43 subjects with a power of 0.8 and an alpha of 0.05 would detect a significant R of 0.42. First, three different measurements of propulsion were calculated for the paretic limb: propulsive impulse (Ns), peak propulsive force (N), and mean propulsive value (N). In addition, each of these measurements of propulsion was multiplied by cadence (steps/s) to generate 3 additional measurements: propulsive impulse*cadence (N*steps), peak propulsive force*cadence (N*steps/s), and mean propulsive value*cadence (N*steps/s). The relationships between self-selected walking speed and each of the above measurements of propulsion were analyzed by using Pearson correlation coefficients to determine whether each measurement was related to individuals' walking speed. Next, the relationships between changes in each measurement of propulsion as individuals modulated their speeds from their self-selected to fast walking speed versus their actual changes in walking speed were analyzed to determine the sensitivity of each measurement to changes in walking speed. Finally, stepwise linear regression analysis was used to determine the strongest predictor for self-selected walking speed and changes in walking speed. In the stepwise linear regression procedure, each variable was entered in sequence and was retained if it contributed significantly to the model. All other variables in the model were re-tested

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