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Limb contribution to increased self-selected walking speeds during body weight support in individuals poststroke

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Abstract

Individuals poststroke walk at faster self-selected speeds under some nominal level of body weight support (BWS) whereas nonimpaired individuals walk slower after adding BWS. The purpose of this study was to determine whether increases in self-selected overground walking speed under BWS conditions of individuals poststroke can be explained by changes in their paretic and nonparetic ground reaction forces (GRF). We hypothesize that increased self-selected walking speed, recorded at some nominal level of BWS, will relate to decreased braking GRFs by the paretic limb. We recruited ten chronic (>12 months post-ictus, 57.5±9.6 y.o.) individuals poststroke and eleven nonimpaired participants (53.3±4.1 y.o.). Participants walked overground in a robotic device, the KineAssist Walking and Balance Training System that provided varying degrees of BWS (0–20% in 5% increments) while individuals self-selected their walking speed. Self-selected walking speed and braking and propulsive GRF impulses were quantified. Out of ten poststroke individuals, eight increased their walking speed 13% ($p=0.004$) under some level of BWS (5% $n=2$, 10% $n=3$, 20% $n=3$) whereas nonimpaired controls did not change speed ($p=0.470$). In individuals poststroke, changes to self-selected walking speed were correlated with changes in paretic propulsive impulses ($r=0.68$, $p=0.003$) and nonparetic braking impulses ($r=-0.80$, $p=0.006$), but were not correlated with decreased paretic braking impulses ($r=0.50$, $p=0.14$). This investigation demonstrates that when individuals poststroke are provided with BWS and allowed to self-select their overground walking speed, they are capable of achieving faster speeds

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Conflict of Interest:

Dr. Brown must disclose that a potential conflict of interest exists with the submission of this manuscript, in that he is a co-inventor of the robotic device that is described in this study and that he may potentially receive royalties on any sales of the device as it is marketed by HDT Robotics, LLC (www.kineassist.com). He is also a paid consultant to HDT. CPH and JKB declare no conflict of interest.

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by modulating braking impulses on the nonparetic limb and propulsive impulses of the paretic limb.

Keywords

body weight support; gait speed; poststroke; ground reaction force

Introduction

Individuals poststroke select slower walking speeds compared to nonimpaired individuals [1]. Inappropriate or mistimed muscular activation can lead to altered gait mechanics [2], resulting in altered ground reaction force (GRF) profiles [3] compared to nonimpaired controls. Individuals poststroke generate relatively larger paretic limb braking forces compared to propulsive forces [3], which could act to limit their self-selected walking speed (SSWS), and is related to the level of chronic gait disability [4].

Under some nominal level of BWS, individuals poststroke walk at faster SSWS [5]. BWS results in reduced lower-limb extensor moment [6], thus theoretically reducing the paretic limb braking impulse. This may allow greater contribution from the paretic limb to forward progression. The purpose of this investigation is to determine whether increases in SSWS under BWS conditions of individuals poststroke can be explained by changes in their paretic and nonparetic GRFs. We hypothesize that increased self-selected walking speed, recorded at some nominal level of BWS, will relate to decreased braking GRFs by the paretic limb.

Methods

Ten chronic (>12 months post-ictus) individuals poststroke with hemiparesis and 11 nonimpaired controls participated in this study. Individuals poststroke were, on average, 57.5 ± 9.6 years old and weighed 80.6 ± 17.8 kg. The average lower-limb assessment of the Fugl-Meyer score, as performed by a research physical therapist, was 22.9 ± 6.5 , range 17–32, out of 34. All participants were consented before participating in this institutionally approved study conducted at Northwestern University. Individuals poststroke were independently ambulatory in the robotic device used for this study (described below), able to follow simple commands and able to visually distinguish force plates. Participants were excluded if they presented with concurrent neurological or cardiovascular conditions, pre-morbid gait disorders, or severe cognitive or affective disorders. Nonimpaired participants had no known neurological disorders, cardiovascular disease, or lower-limb orthopedic conditions. Nonimpaired controls were on average 53.3 ± 4.1 years old and weighed 80.2 ± 19.4 kg.

The KineAssist Gait and Balance Training System™ (HDT Global, Solon OH), (Figure 1) was used [7]. The robotic device interfaced with participants through a pelvic harness instrumented with bi-lateral force sensors that measure vertical and horizontal forces applied to the harness through the pelvis. The measured vertical forces are used within a closed-loop controller to provide a constant level of BWS. A linear relationship exists between the measured horizontal forces and the speed of the overground mobile robotic base [7], which

allows individuals to self-select their walking speed. The robotic device traversed on a 10 m by 0.71 m elevated rail system to avoid contact with the cluster of four forceplates (AMTI, Newton, MA, USA) located midway along the walkway. Instructions were provided to the participants so the kinetics of two succeeding steps could be collected.

The pelvic harness of the Kineassist allowed 6-degrees of freedom. Thus, even though the KineAssist moved along a fixed path, the lateral motion of the center of mass that occurs step-to-step was allowed within the frame of the Kineassist. Individuals performed two trials of four randomly presented BWS conditions of 5, 10, 15, and 20% BWS. Braking and propulsive impulses generated by the limbs were quantified from the fore-aft GRFs recorded from force plates using a custom algorithm in Matlab (MathWorks, Natick, MA, Figure 1 inset). Braking impulse was calculated as the time integral of the negative fore-aft GRF (equation 1) while the propulsive impulse was calculated as the time integral of the positive fore-aft GRF (equation 2).

$$\hat{\Delta} \hat{c} \quad \text{Braking Impulse: } \int (-F_{hGRF}) dt \quad (1)$$

$$\hat{\Delta} \hat{c} \quad \text{Propulsive Impulse: } \int (+F_{hGRF}) dt \quad (2)$$

Walking speed was quantified as the speed of the robotic device using angular measurements of wheel sensors converted to linear motion. The velocity signal was filtered with a 1 Hz low-pass filter. The peak velocity as individuals crossed the force plates was used. Percent change in walking speeds between zero BWS and the fastest speed during some nominal BWS condition was statistically compared by a one-sample t-test for each group in SPSS (IBM, Armonk NY). Changes in braking and propulsive impulses were correlated with changes in walking speed. Correlations were performed with Pearson's r . Significance was set to $p < 0.05$. Tests of normality (i.e. Shapiro-Wilk Test) indicated normal distribution of data related to changes in speed and forces for individuals poststroke and nonimpaired controls ($p > 0.05$).

Results

On average, individuals poststroke walked 9% ($p = 0.004$) faster under some nominal BWS condition (0.63 ± 0.15 m/s to 0.69 ± 0.17 m/s, Figure 2). Out of ten poststroke individuals, eight increased their SSWS 13% with BWS, (0.61 ± 0.14 m/s to 0.69 ± 0.17 m/s), at different percent BWS conditions (2–0%, 2–5%, 2–10%, 1–15%, 3–20%). In contrast, BWS did not alter the average SSWS of nonimpaired individuals (0.80 ± 0.17 m/s vs. 0.82 ± 0.16 m/s, $p = 0.470$).

For individuals poststroke, we did not detect a significant relationship between changes in paretic braking and changes to SSWS (Table I). However, secondary analyses showed a significant relationship between changes to paretic propulsion and nonparetic braking with respect to changes in SSWS (Table I). Lastly, a significant relationship was observed between percent changes in SSWS and the poststroke Fugl-Meyer scores ($r = 0.74$, $p = 0.007$).

Discussion

As previously reported [5], individuals poststroke respond to BWS by self-selecting a faster walking speed whereas, the walking speed in age-matched nonimpaired individuals is not altered. Contrary to our hypothesis, changes in SSWS only correlated to changes in paretic propulsive impulse and nonparetic braking impulse. These results are consistent with previous observations that nonparetic braking and paretic propulsive impulses are related to the SSWS of individuals poststroke [4]. Additionally, individuals with the lowest assessed locomotor impairment (i.e., Fugl-Meyer scores) experience greater increases in SSWS while experiencing BWS. Together, this suggests achieving a desired walking speed requires regulating braking forces as well as propulsive forces with the poststroke impaired nervous system. Our observations that BWS facilitates paretic limb contribution to forward progression of the body may be explained by the reduction of the poststroke nervous system's requirement to provide postural control of vertical support during upright walking. Massion suggests that the neural control of posture and locomotion are separate, but interacting controllers for normal walking [8]. Previously, Liang and Brown suggested that Massion's model may be altered poststroke, such that the requirement for generating vertical support forces during locomotion interferes with regulation of foot force direction [9]. The current study suggests reducing the vertical support requirement of locomotion with BWS may result in less interference of postural control centers on locomotor control.

The number of participants in the current investigation was small and may limit our ability to translate our findings to the larger poststroke population. However the increased walking speed with body weight support we report confirms a previous investigation of another subsample of 11 individuals poststroke [5]. It is also possible that with more participants, the trend we saw related to paretic braking would have achieved a significant difference, however it should be noted that the directionality of the relationship for paretic braking was opposite of what we hypothesized. Future investigations could include kinematic analyses to determine the extent to which individual joints contributed to the increased walking speed we report under some nominal level of body weight support.

Conclusion

When individuals poststroke are provided with BWS and allowed to self-select their walking speed, they are capable of achieving faster speeds by modulating their braking and propulsive impulses in the nonparetic and paretic limb respectively.

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Highlights

- Individuals poststroke self-select faster walking speed with bodyweight support
- Faster speeds were related to modulation of braking and propulsive forces
- Increased paretic propulsion may relate to reduced vertical support requirement

Figure 1.

The experimental setup used for this experiment. The KineAssist follows the individual on a rail system to avoid contact with the cluster of four force plates in the middle of the laboratory walkway. The individual interfaces with the device through a pelvic harness which measures forces applied to the harness with bi-lateral force sensors. Vertical forces are used in a close-loop control to provide bodyweight support. Horizontal forces were converted into a command signal to the wheels of the KineAssist, creating a system whereby individuals can self-select their walking speed. Inset: Example of fore-aft ground reaction forces measured for a step while individuals walked over the cluster of force plates along the walkway.

Figure 2.

Effect of body weight support on self-selected walking speed is displayed. The percent change in walking speed between no body weight support and the nominal level that resulted in the fastest self-selected walking speed is displayed for each participant along with the group average.

Table 1

Correlation of changes in braking and propulsive impulses with changes in walking speed relative to each respective limb. Factors that reached statistical significance ($p < 0.05$) are highlighted in gray.

			Impulse (N·s)/kg	
			Braking	Propulsive
Participant Poststroke	Paretic Limb	Pearson r	0.50	0.68
		p-value	0.15	0.03
	NonParetic Limb	Pearson r	-0.80	-0.34
		p-value	0.01	0.33
Nonimpaired Control	Combined Limbs	Pearson r	-0.02	-0.05
		p-value	0.96	0.89