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Full Length Article

Subtasks affecting step-length asymmetry in post-stroke hemiparetic walking

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ABSTRACT

This study was performed to investigate whether components from trunk progression (TP) and step length were related to step length asymmetry in walking in patients with hemiparesis. Gait analysis was performed for participants with hemiparesis and healthy controls. The distance between the pelvis and foot in the anterior-posterior axis was calculated at initial-contact. Step length was partitioned into anterior foot placement (AFP) and posterior foot placement (PFP). TP was partitioned into anterior trunk progression (ATP) and posterior trunk progression (PTP). The TP pattern and step length pattern were defined to represent intra-TP and intra-step spatial balance, respectively. Of 29 participants with hemiparesis, nine participants showed longer paretic step length, eight participants showed symmetric step length, and 12 participants showed shorter paretic step length. For the hemiparesis group, linear regression analysis showed that ATP asymmetry, AFP asymmetry, and TP patterns had significant predictability regarding step length asymmetry. Prolonged paretic ATP and shortened paretic AFP was the predominant pattern in the hemiparesis group, even in participants with symmetric step length. However, some participants showed same direction of ATP and AFP asymmetry. These findings indicate the following: (1) ATP asymmetries should be observed to determine individual characteristics of step length asymmetry, and (2) TP patterns can provide complementary information for non-paretic limb compensation.

1. Introduction

Patients with post-stroke hemiparesis walk slowly and asymmetrically because of impairments in support function, propulsion function, and swing ability (Balaban & Tok, 2014). Walking speed is considered a well-accepted parameter that reflects overall walking function. However, it has limitations in providing information regarding specific impairments and compensations for individual patients (Lord, Halligan, & Wade, 1998; Olney, Griffin, & McBride, 1994). Many researchers considered asymmetries to be related to impairments and/or compensations (Allen, Kautz, & Neptune, 2011; Balasubramanian, Bowden, Neptune, & Kautz, 2007; Balasubramanian, Neptune, & Kautz, 2010; Chisholm, Perry, & McIlroy, 2011; Kim & Eng, 2003; Patterson, Gage, Brooks, Black, & McIlroy, 2010b; Roerdink & Beek, 2011; Roerdink, Roeles, van der Pas, Bosboom, & Beek, 2012).

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Patients with post-stroke hemiparesis predominantly exhibit patterns of prolonged swing time and shortened stance time in the paretic lower limb (Kim & Eng, 2003; Patterson et al., 2008). These temporal asymmetries negatively correlate with walking speed, motor recovery, and lower limb sensory-motor impairments (Brandstater, de Bruin, Gowland, & Clark, 1983; Chisholm et al., 2011; Patterson et al., 2008). In contrast to temporal asymmetry, step length asymmetry has an inconsistent relationship with walking speed (Balasubramanian et al., 2007; Patterson et al., 2008), showing variable patterns, such as longer, shorter, or symmetric paretic step length compared to non-paretic step length (Allen et al., 2011; Turns, Neptune, & Kautz, 2007). Focusing on these inconsistencies, previous authors have investigated the relationship between step length asymmetry and compensation strategies (Allen et al., 2011; Balasubramanian et al., 2007, 2010; Roerdink & Beek, 2011; Roerdink et al., 2012).

Balasubramanian et al. (2007) reported that paretic step length was longer than non-paretic step length despite weak paretic propulsion function; they suggested that the longer paretic step length was a result of non-paretic limb compensation that increased forward propulsion in the stance phase (Balasubramanian et al., 2007). Allen et al. reported that patients with post-stroke hemiparesis showed a common impairment in the ankle plantar flexion moment impulse but different compensation mechanisms according to the pattern of step length asymmetry as follows: patients with longer paretic step length showed increased non-paretic plantar flexion moment impulse during the late single-leg stance and pre-swing phase; patients with symmetric step length had increased bilateral hip flexion moment impulse; and patients with smaller paretic step did not show a compensatory increase in kinetic variables (Allen et al., 2011). However, no previous study has experimentally confirmed the hypothesis that paretic step length longer than non-paretic step length arises from non-paretic limb compensation that increases the forward progression of the trunk. Hodt-Billington, Helbostad, and Moe-Nilssen (2008) reported that asymmetry in trunk movement was a characteristic finding in patients with chronic stroke. Roerdink and Beek (2011) divided step length asymmetry into trunk forward movement asymmetry and forward foot placement asymmetry and reported that neither were correlated with step length asymmetry; they postulated that trunk forward movement asymmetry and forward foot placement asymmetry contributed to step length asymmetry in an additive or annulled manner (Roerdink & Beek, 2011). Those authors further revealed that symmetric step length does not always represent recovery from compensatory strategy and that partitioning step length into components is essential for understanding individual compensation strategy (Roerdink & Beek, 2011). However, their study had a small sample size.

Total trunk forward movement during a step encompasses forward foot placement of previous step length (Roerdink & Beek, 2011), rendering it difficult to investigate the relationship between trunk forward movement asymmetry and step length asymmetry. In addition, non-paretic limb compensation occurs in the late single stance and pre-swing phase (Allen et al., 2011), implying that trunk forward movement after mid-stance phase reflects non-paretic limb compensation more selectively than total trunk forward movement. Therefore, this study further partitioned trunk forward movement into

Table 1
Definitions of the study variables.

Step length	Distance between the leading and trail limb foot COMs at the initial contact of the leading limb	
AFP	Distance from the leading limb foot COM to the pelvis COM at the initial contact of the leading limb	
PFP	Distance from the pelvis COM to the trailing limb foot COM at the initial contact of the leading limb	
Step-length pattern	Ratio of the AFP to step length (step-length pattern) = AFP/(PFP + AFP)	
TP	Distance of the pelvis COM trajectory during a step	
ATP	Distance from the pelvis COM perpendicular to the stance foot COM to the pelvis COM at the end of step (IC) in the anterior-posterior axis: 2nd part of TP	
PTP	Distance from the pelvis COM at the start of step (IC) to the pelvis COM perpendicular to the stance foot COM in the anterior-posterior axis: 1st part of TP	
Trunk progression pattern	Ratio of ATP to TTP (trunk progression pattern) = ATP/(PTP w + ATP)	
	Non-paretic step length	=non-paretic PFP + non-paretic AFP =non-paretic ATP + paretic PTP =non-paretic ATP + non-paretic AFP
	Paretic step length	=paretic PFP + paretic AFP =paretic ATP + non-paretic PTP =paretic ATP + paretic AFP

Distances were measured on the anterior-posterior (AP) axis. Step length, AFP, and PFP definitions followed those described previously (Balasubramanian, Neptune, & Kautz, 2010). The TP definition was also as defined previously (Roerdink & Beek, 2011). ATP, PTP, step length pattern, and TP patterns were operationally defined. AFP = anterior foot placement, PFP = posterior foot placement, TP = trunk progression, PTP = posterior trunk progression, ATP = anterior trunk progression.