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Applying a pelvic corrective force induces forced use of the paretic leg and improves paretic leg EMG activities of individuals post-stroke during treadmill walking

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HIGHLIGHTS

- A mediolateral assistance force was applied to the pelvis toward the paretic side during walking.
- Applying pelvic assistance may enhance paretic leg muscle activity and improve walking pattern.
- Forceful weight shift to the paretic side could induce forced used of the paretic leg.

ABSTRACT

Objective: To determine whether applying a mediolateral corrective force to the pelvis during treadmill walking would enhance muscle activity of the paretic leg and improve gait symmetry in individuals with post-stroke hemiparesis.
Methods: Fifteen subjects with post-stroke hemiparesis participated in this study. A customized cable-driven robotic system based over a treadmill generated a mediolateral corrective force to the pelvis toward the paretic side during early stance phase. Three different amounts of corrective force were applied. Electromyographic (EMG) activity of the paretic leg, spatiotemporal gait parameters and pelvis lateral displacement were collected.
Results: Significant increases in integrated EMG of hip abductor, medial hamstrings, soleus, rectus femoris, vastus medialis and tibialis anterior were observed when pelvic corrective force was applied, with pelvic corrective force at 9% of body weight inducing greater muscle activity than 3% or 6% of body weight. Pelvis lateral displacement was more symmetric with pelvic corrective force at 9% of body weight.
Conclusions: Applying a mediolateral pelvic corrective force toward the paretic side may enhance muscle activity of the paretic leg and improve pelvis displacement symmetry in individuals post-stroke.
Significance: Forceful weight shift to the paretic side could potentially force additional use of the paretic leg and improve the walking pattern.

1. Introduction

Walking dysfunction is one of the commonly reported physical limitations after stroke (Perry et al., 1995). Individuals with post-stroke hemiparesis typically demonstrate slow gait velocity, reduced stride and step length, and decreased period of stance and increased period of swing of the paretic leg (Balaban and Tok, 2014; Patterson et al., 2010a). As walking dysfunction can increase the risk of falls (Hausdorff et al., 2001), restrict functional mobility and negatively affect quality of life (Maclean et al., 2000; Perry et al., 1995; Schmid et al., 2007), an important goal of stroke rehabilitation is to improve symmetrical gait patterns.

The asymmetrical gait characteristics after stroke are associated with reduced weight bearing toward the paretic leg (Hendrickson et al., 2014; Olney and Richards, 1996; Tyson, 1999) and altered timing and amplitude of paretic leg muscle activation (Burridge et al., 2001; Hsu et al., 2003; Lamontagne et al., 2007). Reduced weight bearing toward the paretic leg may be a consequence of a

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“learned nonuse”, (Aruin et al., 2012) which can be reversed by forced use and intensive function training of the paretic leg (Schaechter, 2004; Taub et al., 2006).

Constraint induced movement therapy has been used to induce a forced use of the paretic arm in individuals with post-stroke hemiparesis (Taub et al., 2006; Wolf et al., 2008). This training paradigm has not been transferred to paretic leg because restraint of the non-paretic leg does not allow bipedal locomotion. Recent studies indicated that using a shoe insole under the non-paretic leg may promote body weight shift towards the paretic leg (Aruin et al., 2012; Mohapatra et al., 2012). However, the positive effects of shoe insole on walking function may be limited (Aruin et al., 2012), suggesting the shoe insole may not be effective in inducing forced use of the paretic leg during locomotion.

It has been reported that giving a downward force on the pelvis could induce a prolonged stance phase of gait in infants (Yang et al., 1998) and enhance soleus muscle activity in neurological intact adults (Stephens and Yang, 1999). Potentially, applying additional loading to the paretic leg during stance phase would enhance muscle activity of the paretic leg. Therefore, the purpose of this study was to determine whether applying a mediolateral corrective force to the pelvis during treadmill walking would facilitate weight shifting toward the paretic leg, and thereby enhance muscle activity of the paretic leg and improve gait symmetry in individuals with post-stroke hemiparesis. The pelvic corrective force was applied through a customized cable-driven robotic system (Wu et al., 2011). We hypothesized that the application of pelvic corrective force toward the paretic side during early stance phase of gait would facilitate weight shifting toward the paretic leg, enhance muscle activity of the paretic leg and improve gait symmetry in individuals with post-stroke hemiparesis.

2. Methods

2.1. Subjects

A total of 15 subjects with hemiparesis due to chronic stroke (>6 months) were recruited from the Sensory Motor Performance Program (SMPP) stroke database and the Rehabilitation Institute of Chicago (RIC) outpatient clinic. Demographic information for the subjects is shown in Table 1. The inclusion criteria were: (1) age 21–75 years, (2) unilateral, supratentorial, ischemic or hemorrhagic stroke confirmed with radiography, (3) no prior history of stroke, (4) independent ambulation with/without the use of assistive device or below knee orthoses, (5) self-selected walking speed $\leq$0.80 m/s. Exclusion criteria were: (1) brainstem or cerebellar stroke, (2) a score on the Mini Mental Status examination <24 (Folstein et al., 1975), (3) other neurological conditions, cardiorespiratory/metabolic disorders, or orthopedic conditions affecting ambulation ability, (4) botox injection within 6 months of study enrollment visit. All subjects received written and verbal information about the study procedure before giving written consent. The study was approved by the Northwestern University Institutional Review Board.

2.2. Experimental apparatus

A customized cable-driven robotic system based over a treadmill was used to generate a corrective force to the pelvis in the mediolateral direction (Fig. 1a). The robotic system consists of 2 nylon-coated stainless-steel cables, driven by 2 motors (AKM 33H, Kollmorgen, Radford, VA) through cable spools that are located on the side of the treadmill. The cables are affixed to a custom waist belt that is strapped to subjects’ pelvis to provide a corrective force during treadmill walking. The pelvis and ankle positions were recorded using 4 custom designed 3-dimensional position sensors (Fig. 1b). Each sensor includes a rod and 2 universal joints attached to the ends of the rod. The universal joints are connected to each side of the custom waist belt and custom ankle straps (Wu et al., 2011). Two potentiometers (P2201, Novotechnik, Southborough, MA) were used to measure rotational movements of the rod in the anteroposterior and mediolateral directions; one potentiometer (SP-2, Celesco, Chatsworth, CA) was used to measure the linear movement of the rod in the diagonal direction. The recorded ankle position signals were used to trigger the corrective force applied from initial contact to mid-stance of the paretic leg. A custom-written LabVIEW program was used to collect pelvis and ankle positions at 500 Hz as well as to command corrective force signals to the motors.

2.3. Experimental procedures

Each subject participated in 5 test sessions on the treadmill, which included 1 session of walking at self-selected comfortable speed (baseline), 1 session of walking at maximum walking speed, and 3 sessions of walking at self-selected comfortable speed with different amounts of corrective force (3%, 6% and 9% of body weight). The order of 3 corrective force sessions was randomized across subjects. For the baseline and maximum walking speed sessions, each session required subjects to walk 30 strides. For the 3 corrective force sessions, each session was 1 min with a 1-min standing rest between sessions. During all sessions, subjects wore

Table 1
Demographic information for the subjects.

Subject	Gender	Age	Weight (kg)	Post injury (yr)	Paretic side	Assistive device	Test speed (m/s)
S1	F	65	66.7	9	R	Rollator/AFO	0.27
S2	M	40	90.7	8	L	AFO	0.62
S3	F	67	64.9	23	L	AFO	0.37
S4	F	54	68.0	5	R	AFO	0.59
S5	M	48	85.7	16	R	AFO	0.46
S6	M	46	67.1	11	L	AFO	0.74
S7	M	66	78.5	3	R	SPC/AFO	0.43
S8	F	46	92.1	9	L	None	0.53
S9	M	74	83.5	6	L	None	0.41
S10	M	67	62.6	2	L	SBQC/AFO	0.33
S11	F	46	51.3	2	L	AFO	0.47
S12	F	56	77.1	2	L	AFO	0.80
S13	F	61	75.8	3	L	SBQC/AFO	0.34
S14	F	65	67.6	1	L	None	0.37
S15	M	43	107.5	8	L	SPC/AFO	0.64

Abbreviations: AFO = ankle foot orthosis; SPC = single point cane; SBQC = small based quad cane.