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Combined Visual Feedback with Pelvic Assistance Force Improves Step Length during treadmill walking in Individuals with Post-Stroke Hemiparesis

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Abstract

Altered spatiotemporal gait characteristics are common impairments after stroke. Visual feedback has been used to improve spatiotemporal gait characteristics. In addition, pelvic assistance force applied in the mediolateral direction to the paretic side can improve walking pattern. Potentially, combined visual feedback and pelvic assistance force can have better rehabilitation outcomes on walking patterns. The purpose of this study was compare the effects of combined visual feedback with pelvic assistance force and visual feedback only during treadmill walking in individuals with post-stroke hemiparesis. Fifteen subjects with hemiparesis due to chronic (>6 months) stroke participated. A computer monitor placed in front of the treadmill was used to provide visual feedback on subjects' weight bearing on the paretic leg. A customized cable-driven robotic system was used to apply pelvic assistance force. The magnitude of pelvic assistance force was 9% of body weight. The session consisted of 5 sections: 1-min baseline, 7-min treadmill training (visual feedback only or combined visual feedback and pelvic assistance force), 1-min post-training (no visual feedback or pelvic assistance force), 1-min standing break, and 5-min treadmill training. The order of the visual feedback only and combined visual feedback and pelvic assistance force sessions was randomized across subjects. Spatiotemporal gait variables within the session, including stance time, single leg support time and step length, were computed. Combined visual feedback with pelvic assistance force resulted in a better improvement in step length of the paretic leg when compared to visual feedback only ($p=0.03$). Walking patterns after stroke could potentially be improved by applying visual feedback regrading paretic leg weight bearing and pelvic assistance force. Future study is needed to confirm the effectiveness of visual feedback for treadmill training after stroke.

I. INTRODUCTION

Hemiparesis after stroke can significantly contribute to walking impairments [1]. Individuals with post-stroke hemiparesis demonstrate slow gait speed and altered spatiotemporal gait characteristics [2]. As walking impairments can negatively impact functional mobility [3], [4], rehabilitation interventions that improve walking patterns after stroke are highly desirable. Altered spatiotemporal gait characteristics after stroke are associated with reduced weight shifting toward the paretic leg [5], [6], which may be a consequence of a “learned nonuse” [7] and can be reversed by forced use of the paretic leg. Use of visual feedback has been considered as an effective approach to improve spatiotemporal gait characteristics during locomotor training [8]. Our previous study applied a mediolateral assistance force to the pelvis during treadmill walking to force use of the paretic leg and showed an improvement in pelvis displacement symmetry [9]. It is unclear whether combined visual feedback and pelvic assistance force during locomotor training can have better walking patterns.

The purpose of this study was to compare the effects of combined visual feedback with pelvic assistance force and visual feedback only during treadmill walking in individuals with post-stroke hemiparesis. We hypothesized that combined visual feedback with pelvic assistance force would result in greater improvements in spatiotemporal gait characteristics than visual feedback only in individuals with post-stroke hemiparesis.

II. METHODS

A. Subjects

Subjects with post-stroke hemiparesis (> 6 months) were recruited from the Shirley Ryan AbilityLab outpatient clinic. 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 ≥ 0.80 m/s. Exclusion criteria were: (1) brainstem or cerebellar stroke, (2) a score on the Mini Mental Status examination < 24, (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.

B. Experimental Apparatus

Weight bearing on the paretic leg was monitored by mobile SmartStep device (version 2.20, Andante Medical Devices). The SmartStep is a portable biofeedback system that consists of a pneumatic insole measuring the vertical force under the forefoot and hindfoot at a frequency of 40 Hz. The vertical force data were transmitted to a computer through wireless technology and displayed on a TV screen (52”). The TV screen was placed in front of the treadmill to provide real-time feedback on subjects’ weight bearing on the paretic leg.

A customized cable-driven robotic gait training system was used to generate an assistance force to the pelvis in the mediolateral direction (Fig. 1). 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 2 sides of the treadmill. The cables are affixed to a custom waist belt that is strapped to subjects' pelvis to provide an assistant force during treadmill walking. The pelvis and ankle positions were recorded using 4 custom designed 3-dimensional position sensors. The recorded ankle position signals were used to trigger the pelvic assistance force. A custom-written LabVIEW program was used to collect pelvis and ankle positions at 500 Hz as well as to command force signals to the motors.

C. Experimental Procedure

Each subject participated in 2 test sessions on the treadmill, which included 1 session of visual feedback only (VISUAL) and 1 session of combined visual feedback and pelvic assistance force (COMBINED). The order of 2 test sessions was randomized. Each test session was 15 mins with a 10-min sitting break between sessions. The test session consisted of 5 sections, including 1-min baseline (no visual feedback or pelvic assistance force), 7-min locomotor training (visual feedback or combined visual feedback and pelvic assistance force), 1-min post-training (no visual feedback or pelvic assistance force), 1-min break, and 5-min locomotor training (visual feedback or combined visual feedback and pelvic assistance force). The treadmill speed was set at subjects' self-selected comfortable speed and was the same for 2 test sessions. Subjects wore an overhead harness for safety and no body weight support was provided.

Visual feedback was provided through the TV screen that displayed vertical bar graphs corresponding to subjects' weight bearing of the paretic leg. The target weight bearing was displayed as a horizontal line on the TV screen and set at 120% of weight bearing on the paretic leg during baseline. When subjects exceeded the target weight bearing, the vertical bar would go above the horizontal line and a beep sound would be generated by the computer.

Pelvic assistance force was provided through the robotic system from heel contact to mid-stance of the paretic leg. The magnitude of pelvic assistance force was set at 9% of subjects' body weight, although this was adjusted if subjects could not tolerate it.

D. Data and Statistical Analysis

Spatiotemporal gait parameters, including stance time, single leg support time and step length, were computed using ankle position signals. The ankle position signals were low-pass filtered using the 4th order Butterworth filter with a cutoff frequency at 10Hz using custom written software (version 7.1, The Mathworks, Natick, MA). Stance time was defined as the time from heel contact to toe-off. Single leg support time was defined as the amount of time that spend during the period when only one leg was on the treadmill in a gait cycle. Both stance time and single leg support time were normalized to the whole gait cycle time (% gait cycle). Step length was defined as the anteroposterior distance between the two legs' ankle positions at heel contact.

Spatiotemporal gait parameters were analyzed and averaged for last 5 strides at baseline (BASELINE1), first and last 5 strides at 7-min locomotor training (TRAINING1 and TRAINING2), and first 5 strides at post-training (BASELINE2). Changes in spatiotemporal gait parameters were calculated as $[(\text{TRAINING1} - \text{BASELINE1})/\text{BASELINE1}] * 100$, $[(\text{TRAINING2} - \text{BASELINE1})/\text{BASELINE1}] * 100$, and $[(\text{BASELINE2} - \text{BASELINE1})/\text{BASELINE1}] * 100$. Paired-sample t-tests were used to compare changes in spatiotemporal gait parameters between VISUAL and COMBINED.

III. RESULTS

A total of 15 subjects (8 males) with post-stroke hemiparesis participated. Eleven subjects walked with an ankle foot orthosis and 3 subjects walked with an ankle foot orthosis and a single point cane. The average treadmill walking speed was 0.52 (0.12) m/s.

Spatiotemporal gait parameters are shown in Fig. 2 to Fig. 4. Changes in spatiotemporal gait parameters were not significantly different between the VISUAL and COMBINED (Table I), except the change in step length from BASELINE1 to TRAINING 1 between the VISUAL and COMBINED. Specifically, step length of the paretic leg significantly improved from BASELINE1 to TRAINING1 in COMBINED when compared to VISUAL ($P=0.03$).

IV. DISCUSSION

The results of this study indicated that combined visual feedback and pelvic assistance force improved step length of the paretic leg when compared to visual feedback only in subjects with post-stroke hemiparesis. While individuals with post-stroke hemiparesis may walk with either relatively longer paretic or non-paretic steps, our subjects walked with shorter paretic steps and longer non-paretic steps at baseline. Our combined treatment strategy has the potential to be effective at improving step length symmetry after stroke.

Combined visual feedback and pelvic assistance force appears to be more effective than visual feedback only in increasing weight shifting toward the paretic leg. Visual feedback alone might not be enough for subjects to voluntarily transfer their body weight to the paretic side due to impairments in weight-transfer capabilities [10]. Providing both visual feedback and pelvic assistance force facilitates use of the paretic leg during paretic stance, which might increase paretic leg loading. Increased paretic leg loading might enhance paretic leg hip extension. Paretic leg might be pulled into more hip extension with the movement of treadmill belt, which could lead to a stretch of hip flexor, induce paretic leg to step forward and further increase the step length. It is also possible that the increased leg loading enhanced muscle activities of ankle plantarflexors [9], which improves subjects' ability to generate forward propulsion of the paretic leg to increase the step length of the paretic leg.

While both feedback and feedforward control mechanisms might be involved in response to visual feedback and pelvic assistance force, our results suggest that feedback control mechanism seems to provide more contributions to the responses because we did not observe an increase in step length of the paretic leg during BASELINE 2 when the visual feedback and pelvic assistance force were removed.

This study has limitations to consider when interpreting the results. We did not include a comparing session with pelvic assistance force only. It is unknown whether the improvement in step length would be achieved with pelvic assistance force only. Pelvic assistance force instead of visual feedback might be the main contributor to the improvement in step length. Future research is needed to confirm the effectiveness of visual feedback during treadmill training after stroke. The improvement in step length was only found in the first 5 strides after the visual feedback and pelvic assistance force were provided. A prolonged exposure to an assistance force may possibly elicit adaptation if the assistance force is constant in magnitude. Future research could be designed to examine if gradually increase the magnitude of pelvic assistance force can lead to improvements in spatiotemporal gait characteristics after the visual feedback and pelvic assistance force are removed.

V. CONCLUSION

Combined visual feedback with pelvic assistance force resulted in a greater improvement in step length of the paretic leg in individuals with post-stroke hemiparesis when compared to visual feedback only. Walking patterns after stroke could potentially be improved by applying visual feedback regrading paretic leg weight bearing and pelvic assistance force. Our combined treatment strategy may provide insights into the development of gait training protocols for improving walking patterns in both research and clinical settings.

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Figure 1.
Application of visual feedback and pelvic assistance force

Figure 2. Stance time of the paretic leg for VISUAL and COMBINED. Data are presented in mean and standard deviation.

Figure 3.

Single leg support time of the paretic leg for VISUAL and COMBINED. Data are presented in mean and standard deviation.

Figure 4. Step length of the paretic leg for VISUAL and COMBINE. Data are presented in mean and standard deviation.

TABLE I.

CHANGES IN SPATIOTEMPORAL GAIT PARAMETERS FOR VISUAL AND COMBINED

Change (%)	TRAINING1-BASELINE1		TRAINING2-BASELINE1		BASELINE2-BASELINE1	
	VISUAL	COMBINED	VISUAL	COMBINED	VISUAL	COMBINED
Stance time	-0.29 (1.31)	0.70 (3.35)	0.55 (2.70)	0.45 (2.49)	-0.29 (4.18)	-0.16 (2.52)
Single leg support time	1.57 (5.79)	3.06 (4.67)	-1.62 (9.84)	3.06 (6.25)	0.41 (3.93)	0.74 (3.37)
Step length	-0.11 (5.53)	8.32 (10.70)	1.28 (9.39)	4.08 (12.40)	-3.46 (10.94)	-6.37 (18.44)