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Influence of visual feedback on dynamic balance control in chronic stroke survivors

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ABSTRACT

Chronic stroke survivors have an increased incidence of falls during walking, suggesting changes in dynamic balance control post-stroke. Despite this increased incidence of falls during walking, balance control is often studied only in standing. The purpose of this study was to quantify deficits in dynamic balance control during walking, and to evaluate the influence of visual feedback on this control in stroke survivors. Ten individuals with chronic stroke, and ten neurologically intact individuals participated in this study. Walking performance was assessed while participants walked on an instrumented split-belt treadmill with different types of visual feedback. Dynamic balance control was quantified using both the extent of center of mass (COM) movement in the frontal plane over a gait cycle (COM sway), and base of support (step width). Stroke survivors walked with larger COM sway and wider step widths compared to controls. Despite these baseline differences, both groups walked with a similar ratio of step width to COM sway (SW/COM). Providing a stationary target with a laser reference of body movement reduced COM sway only in the stroke group, indicating that visual feedback of sway alters dynamic balance control post-stroke. These results demonstrate that stroke survivors attempt to maintain a similar ratio of step width to COM movement, and visual cues can be used to help control COM movement during walking post-stroke.

1. Introduction

Visual feedback provides important information about the walking environment, which can then be used to update dynamic balance control and avoid potential falls in stroke survivors. Stroke survivors have a higher occurrence of falls (Jørgensen et al., 2002), with many of these falls occurring during walking (Mackintosh et al., 2005). Additionally, walking function post-stroke is strongly predicted by clinical measures of balance control (Michael et al., 2005). Improvements in both standing balance control and walking function are observed when rehabilitation techniques targeting sensorimotor integration are combined with traditional standing balance exercises post-stroke (Smania et al., 2008). However, despite an increased reliance on visual feedback for balance control (Slaboda et al., 2009), it is unknown whether altered visual feedback can be used to improve dynamic balance control and walking function for stroke survivors.

Balance control during walking is largely focused on frontal plane instability (Bauby and Kuo, 2000), and is complicated by both center of mass (COM) translation, and base of support variations in size and position. Lateral foot placement adjustments to keep the COM within the base of support are the most effective mechanism for dynamic balance control during walking (Hof, 2008). Visual feedback signals are an integral part of this lateral foot placement control, both during a step (Reynolds and Day, 2005), and over the course of multiple steps (Marigold and Patla, 2008). Clinically, stroke survivors are often observed watching their feet while walking, presumably using visual cues to aid in stepping. Even with this additional feedback, stroke survivors have difficulties making visually-guided medial–lateral step corrections with the paretic limb (Nonnekes et al., 2010), and walk with asymmetries in medial–lateral foot placement relative to the pelvis (Balasubramanian et al., 2010). These findings suggest that impairments in foot placement control, and likely dynamic balance control, persist even with vision of the feet.

In addition to guiding foot placement, visual feedback might aid in controlling COM movement by providing feedback of body position during walking. Stroke survivors demonstrate increased levels of frontal plane COM movement during quiet standing, with further increases observed when visual feedback is removed (Marigold and Eng, 2006a). Deficits in trunk (Ryerson et al., 2008) and whole body (Rao et al., 2010) position sense post-stroke likely

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contribute to an increased reliance on visual feedback for COM control (Slaboda et al., 2009). This increased reliance on visual feedback may provide a mechanism to improve balance control. For example, providing visual feedback of center of pressure location during standing significantly reduces frontal plane sway in chronic stroke survivors, although sway is still greater than controls (Dault et al., 2003). During walking, young individuals are able to utilize multi-sensory feedback of trunk position to improve trunk control (Verhoeff et al., 2009). However, it is unknown whether stroke survivors can utilize similar strategies to improve dynamic balance control during walking.

In this study we assessed walking performance with and without visual feedback of COM movement in stroke survivors. We hypothesized that visual feedback of body movement would reduce frontal plane COM movement in chronic stroke survivors during walking, with the largest improvements when a stationary visual reference was provided.

2. Methods

2.1. Participants

Ten chronic (> 6 month) stroke survivors with unilateral brain injury, and ten age and sex-matched neurologically intact individuals participated in this study. Exclusion criteria for this study included inability to walk independently (with or without use of an assistive device), lesion to brainstem centers, diagnosis of other neurologic disorders, or inability to provide informed consent. Prior to beginning the experimental session, a licensed physical therapist conducted a clinical evaluation of the stroke participants, consisting of the lower extremity Fugl-Meyer Test (Fugl-Meyer et al., 1975), Berg Balance Assessment (Berg et al., 1992), Dynamic Gait Index (Jonsdottir and Cattaneo, 2007), and 10 m walking test (Mudge and Stott, 2009). Only self-selected overground walking speed was obtained for control participants. Participant characteristics are summarized in Table 1. The Marquette University Institutional Review Board approved all experimental procedures, and written informed consent was obtained from all individuals participating in this study.

2.2. Experimental protocol

Walking trials were conducted on an instrumented split-belt treadmill (FIT, Bertec Inc., Columbus, OH) with both belts set to the same speed. Belt speed was determined after a period of acclimatization at the beginning of the session, during which treadmill speed was slowly increased until participants self-selected the most comfortable speed. This self-selected belt speed was used for all the subsequent walking trials (see Table 1). Individuals were placed in a fall arrest harness, and held onto a side handrail with the non-paretic hand for safety. The handrail was instrumented with a six DOF load cell (MC3A-250, AMTI, Watertown, MA) to quantify handrail forces and torques throughout the trials. Control participants held onto the handle with the hand opposite of the randomly chosen test leg, maintaining consistency between groups.

Walking performance was evaluated under six experimental conditions altering the amount and type of visual information provided during walking. An initial period of treadmill walking was completed to obtain a baseline measure of walking performance prior to the altered visual feedback conditions. During the initial period, participants viewed an unmarked wall 3.8 m in front of the treadmill, with room lighting dimmed. In the reduced vision condition, visual feedback of foot placement was removed by having the individual wear goggles with black tape obstructing the lower half of the visual field. These goggles blocked the view of the participant's legs, while maintaining visual feedback of body motion relative to the room. Augmented visual feedback was provided through the use of a laser attached to a headband, which produced a visible circle ($r=0.01$ m) on the wall in front of the treadmill (3.8 m). Movement of the circle was related to the movement of the participant's head (and body) during walking. First, normal walking and reduced visual feedback trials were conducted, both with and without the laser feedback. In the initial laser-walking trials, the laser was turned on for the duration of the walking trial, but the participant was given no explicit instruction on use of the laser. These trials were conducted to evaluate the effect of providing an additional visual source of body movement and orientation on COM movement during walking without an explicit reference point. After these trials were completed, two laser target trials were conducted to determine whether stroke survivors could use position feedback from the laser to reduce COM movement during walking. During these target trials, a projector mounted above the treadmill displayed a target on the wall in front of the treadmill that either remained stationary or moved during the trial. The stationary target trial consisted of a large circular target ($r=0.22$ m) that the participant was instructed to keep the laser within, while walking. This trial provided a stationary reference point for the visual feedback signal, while also encouraging the participant to actively attend and control the movement of the laser using compensatory head movements, or by reducing body sway. During the moving target condition, a smaller target ($r=0.06$ m) randomly moved through a 1.5 by 1.0 m area on the wall, with the position changing every 1.0–2.0 s. This moving target would require the participant to actively attend and control head movement to adjust the laser's position, while the target's movement would potentially act to destabilize balance control. The center of the stationary target, and middle of the moving target area were located approximately at the center of the visual field when looking straight ahead.

Throughout all walking trials, walking performance was characterized over a period of 100 gait cycles at the participant's self-selected, comfortable treadmill speed. Fifteen passive infrared reflective markers were placed at anatomical locations according to the Plug-In-Gait model (Davis et al., 1991), with an additional seven markers placed at the left and right shoulder, C7, and four markers placed on the head. A six camera Vicon motion capture system (Vicon Motion Systems Ltd., Oxford, UK) recorded marker location at 100 Hz. Treadmill ground reaction forces, and handrail forces were collected at 1000 Hz using a Vicon Mx Giganet to synchronize the analog and video data.

2.3. Data analysis

The data were initially processed in Vicon Nexus software to label markers, visually indicate gait events, and run the lower extremity Plug-In-Gait model.

Table 1
Participant characteristics. Lower extremity Fugl-Meyer (LE FM) maximum 34, Berg Balance maximum 56, Dynamic Gait Index (DGI) maximum 24.

ID	Sex	Age [yrs]	Time post-stroke [months]	Affected side	LE FM	Berg	DGI	Overground walking speed [m/s]	Treadmill speed [m/s]
S01	M	54	71	L	24	49	15	0.988	0.55
S02	F	62	317	L	19	46	21	0.837	0.36
S03	F	55	30	R	31	56	24	1.271	0.63
S04	M	54	42	L	30	43	17	1.136	0.48
S05	F	65	117	L	32	55	23	1.298	0.60
S06	F	62	144	R	32	49	21	1.270	0.58
S07	M	62	95	L	21	39	14	0.502	0.29
S08	M	59	120	R	29	46	21	1.361	0.75
S09	F	54	68	L	28	41	17	0.635	0.30
S10	M	65	7	R	27	54	19	0.995	0.65
C01	M	56	–	–	–	–	–	1.471	1.00
C02	F	62	–	–	–	–	–	1.212	0.96
C03	F	54	–	–	–	–	–	1.212	0.85
C04	M	57	–	–	–	–	–	1.515	0.90
C05	F	66	–	–	–	–	–	1.242	1.00
C06	F	61	–	–	–	–	–	1.299	0.75
C07	M	63	–	–	–	–	–	1.429	0.95
C08	M	58	–	–	–	–	–	1.333	0.90
C09	F	54	–	–	–	–	–	1.325	0.95
C10	M	63	–	–	–	–	–	0.980	0.84