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Changes in center of pressure displacement with the use of a foot drop stimulator in individuals with stroke

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ABSTRACT

Background: Center of pressure measured during gait can provide information about underlying control mechanisms and the efficacy of a foot drop stimulator. This investigation evaluated changes in center of pressure displacement in individuals with stroke with and without a foot drop stimulator.
Methods: Individuals with stroke-related foot drop (n = 11) using a foot drop stimulator and healthy controls (n = 11). Walking speed and bilateral center of pressure variables: 1) net displacement; 2) position and maximum displacement; and 3) mean velocity during walking.
Findings: On the affected limb with the foot drop stimulator as compared to the affected limb without the foot drop stimulator: 1) increased anterior/posterior maximum center of pressure excursion 8% during stance; 2) center of pressure at initial contact was 6% more posterior; 3) medial/lateral mean, maximum and minimum center of pressure position during stance all significantly decreased; 4) anterior/posterior net displacement increased during stance and single support; and 5) anterior/posterior velocity of the center of pressure increased during stance.
Interpretation: Individuals with stroke using a foot drop stimulator contacted the ground more posterior at initial contact and utilized more of the anterior/posterior plantar surface of the foot on the affected limb during stance. With the foot drop stimulator there was a shift in center of pressure toward the medial side possibly indicating an improvement in equinovarus gait where there is a tendency to load the lateral foot throughout stance. For individuals with stroke a foot drop stimulator can improve displacement of the center of pressure which indicates improved forward progression and stability during walking.

1. Introduction

Hemiplegia of the lower limb is one of the most serious and common disabling impairments resulting from stroke (American Heart Association, 2014). Hemiplegic gait is characterized by poor single limb stance and difficulty controlling forward progression (Perry, 1969). Foot drop secondary to stroke, results from weakness or lack of voluntary control in the ankle and toe dorsiflexor muscles. During walking this results in ineffective ankle dorsiflexion during swing and failure to achieve heel strike at initial contact (Burridge and Mclellan, 2000; Stein et al., 2010); these disturbances in healthy walking patterns contribute to decreased speed, a disruption in weight acceptance and weight transfer, and an inefficient and unstable gait (Burridge and Mclellan, 2000; Nolan and Yarossi, 2011a,b).

The standard of care for treating foot drop in chronic stroke has been the application of an ankle foot orthosis (AFO) to assist with ambulation. The AFO traditionally places the ankle in a neutral fixed position (~90°, dorsiflexed) and passively compensates for foot drop throughout the gait cycle (Stein et al., 2010). Existing literature evaluating gait biomechanics indicates that applying an AFO in individuals with stroke can improve gait speed at the expense of ankle range of motion and power generation during push-off (Fatone and Hansen, 2007; Perry and Burnfield, 2010). Although the AFO can mitigate some of the walking difficulty, as a rehabilitation intervention it is not targeted to provide or preserve dynamic function. An alternative rehabilitation approach is to apply functional electrical stimulation (FES) to the common peroneal nerve to help provide active movement during ambulation (Bethoux et al., 2014, 2015; Everaert et al., 2013; Sabut et al., 2010; Stein et al., 2010). The stimulation paradigm for FES is to elicit task-specific movement patterns that result in dynamic functional activity (Daly and Ruff, 2007).

Commercially available foot drop stimulators (FDS) can be specifically programmed to provide active dorsiflexion at the correct timing

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and phase of gait through surface stimulation. The FDS is an alternative to traditional AFOs. FDS technology provides electrically induced muscle activation during the swing phase of gait and at initial contact. Ankle–foot movements are actively produced using the FDS in contrast to the rigid compensatory assistance provided through an AFO (Burridge et al., 2007; Pilkar et al., 2014). Depending on the placement of the electrodes, ankle dorsiflexion can be combined with eversion. Added eversion can provide ankle stability during foot contact and weight acceptance (Stein et al., 2010).

FDS technology provides dynamic movements to the ankle–foot complex. Previous research evaluating the immediate orthotic effect has shown only small changes in walking speed, improved dorsiflexion angle, and improved temporal–spatial characteristics (Knutson and Chae, 2010; Kottink et al., 2007; Sabut et al., 2010; Taylor et al., 1999a,b). These results demonstrate the efficacy for FDS utilization in poststroke rehabilitation but they fail to precisely indicate how FDS technology can improve gait mechanisms by helping to restore or maintain function (Everaert et al., 2013; Stein et al., 2010).

Measurements of the center of pressure (CoP) have been used previously to characterize hemiplegic gait and orthotic interventions (Fatone et al., 2009; Mizelle et al., 2006). The CoP represents the cumulative neuromuscular response that controls center of mass (CoM) movement to help maintain forward progression and balance (Chisholm et al., 2011). Changes in anterior/posterior (AP) CoP during stance can provide precise information on the control of forward progression. Modifications to the medial/lateral (ML) CoP may indicate changes in the control process that regulate lateral stability or the ability to transfer weight between legs during gait (Chisholm et al., 2011).

Previous research evaluating CoP in individuals with stroke and AFO intervention have described a smoother anterior progression of the CoP, elimination of posterior directed movement of the CoP during weight acceptance, and a larger CoP displacement (Fatone and Hansen, 2007; Mizelle et al., 2006; Mueller et al., 1992). CoP is a robust and comprehensive measure that can demonstrate the efficacy of FDS technology for individuals with foot drop and provides precise quantifiable information on performance and function during gait (Mizelle et al., 2006). There is limited research evaluating the effect of FDS on CoP during walking gait in individuals with hemiplegia.

Precise changes in the CoP during gait can provide information about underlying control mechanisms of the neuromuscular system and have been previously used to characterize hemiplegic gait (Mizelle et al., 2006). The purpose of this investigation was to evaluate changes in center of pressure displacement during walking in individuals with stroke, with and without a foot drop stimulator (FDS) and in healthy controls.

2. Methods

2.1. Participants

Individuals with hemiplegia and foot drop secondary to stroke (>3 months) and healthy controls were recruited for participation. Individuals with stroke were recruited from a larger multi-site clinical trial. All participants with stroke were currently using a commercially available foot drop stimulator (FDS) (WalkAide®, Innovative Neurotronics, Inc., Austin, TX, USA) for assistance with gait deviations. Individuals with stroke were able to walk independently for 10 m without FDS.

2.2. Foot drop stimulator (FDS)

The WalkAide® is a battery operated, single-channel, asymmetrical biphasic stimulator with programmable pulse width and frequency that is utilized during walking as a functional electrical stimulation (FES) orthotic device (Melo et al., 2015). This small device (87.9 g, 8.2 cm(H) × 6.1 cm(W) × 2.1 cm(T)) attaches to a molded cuff located just below the knee (Fig. 1). Two surface electrodes are specifically placed near the head of the fibula, directly over the motor nerve and proximal musculature. FES is applied to the peroneal nerve during the gait cycle with programmable timing, intensity and duration controlled by a tilt sensor and accelerometer. The foot drop stimulator (FDS) provides electrically induced muscle activation during the swing phase of gait and at initial contact. The selected technology does not rely on a foot switch, telemetry or external wires in order to initiate dorsiflexion and does not restrict the user to a particular plantar surface area to initiate dorsiflexion. Each participant with stroke used their own WalkAide® device that they normally used for daily ambulation for all walking tests. Each device had been previously custom programmed (stimulus intensity and timing of muscle activation) by a licensed clinician.

2.3. Procedures

Individuals in the stroke group completed four 5-meter walks (2 with FDS and 2 without FDS) at a self-selected speed on level ground. The healthy control (HC) group performed a 2-minute walk as part of a larger research study at a self-selected pace and data from the first 18 s of the walking test were used for analysis.

Participants wore neutral walking shoes with average heel heights for all walking tests and no comparisons were made to a barefoot condition. Members of the study team provided supervision and non-contact guarding during all walking tests for safety. All procedures performed in this investigation were approved by the Human Subjects Review Board and informed consent was obtained prior to study participation.

Wireless plantar pressure data were collected bilaterally at 100 Hz using the pedar®-X Expert System (Novel GmbH, Munich, Germany) during walking tests. The insole sensor technology allows for bilateral analysis of multiple steps. Using the pedar®-X, force is calculated by multiplying the recorded pressure by the sensor area resulting in a force "normal" to each sensor in the matrix (Kernozek et al., 1996). Using pressure data from each of the 99 sensors, the centroid of the pressure distribution is provided in terms of x and y insole coordinates for each foot independently. The origin (0, 0) was defined at the point most medial and posterior with reference to the insole, regardless of foot orientation and line of progression (Chisholm et al., 2011). Increased x-coordinate indicated a movement toward the lateral border of the insole and increased y-coordinate indicated a movement toward the anterior border.

2.4. Data analysis and outcome measures

Demographic information including age, gender, and time since stroke were collected and verified with medical records. Data from all assessments are presented as mean (standard deviation).

Fig. 1. Foot Drop Stimulator (WalkAide®, Innovative Neurotronics, Inc., Austin, TX, USA).