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Perception of lower extremity loads in stroke survivors

Virginia W. Chu [a,*], T. George Hornby [a,b], Brian D. Schmit [a,c]

[a] Sensory Motor Performance Program, Rehabilitation Institute of Chicago, Chicago, IL, United States
[b] Department of Physical Therapy, University of Illinois at Chicago, Chicago, IL, United States
[c] Department of Biomedical Engineering, Marquette University, Milwaukee, WI, United States

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HIGHLIGHTS

- A new method of measuring lower extremity dynamic load perception during gait is developed.
- Load perception impairments in stroke survivors not detected by static tests were significant in our dynamic load perception test.
- Impairments in dynamic load perception correlated with gait asymmetry in stroke survivors.

ABSTRACT

Objective: This study aimed to improve our understanding of static and dynamic lower extremity sensory perception and the impact of sensory impairments on the control of walking in stroke survivors.
Methods: Using a custom, real-time unloading system, we tested load perception at heel strike, mid stance and push off in 10 stroke survivors and compared their performance to 10 age-matched and 5 young adult control subjects. Dynamic load perception was based on a judgment of which leg was bearing more load, which was altered on a step by step basis. We also examined lower extremity static load perception, coordination, proprioception, balance, and gait symmetry.
Results: The stroke survivors performed significantly worse than the control subjects in dynamic load perception, coordination, proprioception, balance and gait symmetry. Gait symmetry correlated with static and dynamic load perception measures but not with age, proprioception, coordination, and balance.
Conclusions: Sensory deficits related to load detection in the impaired limb could result in an increased uncertainty of limb load and a gait strategy in which stroke survivors minimize loading of the impaired limb.
Significance: This new method of measuring lower extremity dynamic load perception provides a framework for understanding gait-related sensory impairments in stroke survivors.

1. Introduction

The loss of load perception in the impaired leg likely impacts control of walking in stroke survivors (Bohannon, 2003). While the gait impairments experienced by stroke survivors could result directly from damage to motor areas of the brain (Collen et al., 1990; Enzinger et al., 2008), the lack of proper inputs from the environment (sensory information) clearly has an impact on the body's ability to control movement. In order to walk without losing balance, the motor control system needs to receive accurate sensory information from the limbs. Similarly, we would expect that a lack of accurate sensory information could lead to imbalance and asymmetries in gait. Both sensory impairments (Carey, 1995; Carey et al., 1996; Kim and Choi-Kwon, 1996; Tyson et al., 2008) and gait asymmetry (Wall and Ashburn, 1979; Dettmann et al., 1987; Morita et al., 1995; Titianova and Tarkka, 1995) have been well documented in stroke survivors but there has not been an attempt to study the relationship between the two.

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[*] Corresponding author. Tel.: +1 773 888 2248.
E-mail address: virginiawtchu@gmail.com (V.W. Chu).

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Sensory dysfunction is estimated to be present in more than half of stroke survivors (Carey, 1995; Carey et al., 1996; Tyson et al., 2008). This sensory dysfunction has been documented primarily as a loss of proprioception, with most proprioceptive tests in the post-stroke population involving limb position sense and the sensation of movement (Bohannon, 2003; Sullivan and Hedman, 2008). About 36–54% of stroke survivors demonstrate some loss of limb position sense (Shah, 1978; Smith et al., 1983; Carey, 1993). Other sensory impairments after stroke include deficits in tactile discrimination (Kim and Choi-Kwon, 1996), and impairments in vision, hearing, smell and taste (Bohannon, 2003). While these measurements of sensory loss are important, quantification of perception of limb loading has been extremely limited, despite the possible effects it could have on the control of standing or walking, as the significant role of limb loading in the regulation of gait has been previously illustrated in animal research (Duysens et al., 2000).

The effect of load perception on the control of walking can be appreciated by its likely relationship to gait asymmetry in stroke survivors. Gait asymmetry in stroke survivors has been reported in the temporal, spatial and kinetic domains. The step-length ratio between the paretic and non-paretic limb is approximately 1.13 (Dettmann et al., 1987). The paretic limb also has a shorter stance time, prolonged swing time and decreased ground reaction forces relative to the non-paretic limb (Wall and Ashburn, 1979; Morita et al., 1995; Titianova and Tarkka, 1995; Bohannon, 2003). An asymmetrical gait is poor for balance and energetically inefficient (Winter, 1978; Lowery, 1980; Olney et al., 1986; Iida and Yamamuro, 1987; Olney and Richards, 1996), making it an important target for rehabilitation training. Researchers have proposed various factors as the cause for post-stroke gait asymmetries, including spasticity (Dietz and Berger, 1984; Bohannon et al., 1987; Hsu et al., 2003), muscle weakness (Tang and Rymer, 1981; Bourbonnais and Vanden Noven, 1989; Olney et al., 1991), inappropriate co-contraction (Knutsson and Richards, 1979; Conrad et al., 1985) and reduced voluntary drive from the central nervous system (McComas et al., 1973). However, these factors do not fully explain the asymmetries observed in post-stroke gait (Hsu et al., 2003). We believe that limb load perception also has an important role in maintaining gait symmetry, and has been left out of previous studies of gait symmetry.

This study is the first to specifically examine load perception during walking in stroke survivors. We examined both static load perception and dynamic load perception (i.e. during walking). We recruited 10 stroke survivors, 10 age-matched neurologically-intact controls and 5 young adult controls in order to test the effects of stroke and age on lower extremity load perception. We used a motorized body weight support system to manipulate the weight bore by each leg during walking to test dynamic load perception. Further, we examined lower extremity coordination, proprioception, force detection, balance, static standing weight distribution and loading symmetry during gait. In the stroke survivors, we also examined their knee strength, and administered the sensory and motor subsections of the Fugl-Meyer Test (Fugl-Meyer et al., 1975) for the lower extremities and the Modified Ashworth scale (Bohannon and Smith, 1987) to measure spasticity. We hypothesized that sensory deficits in stroke survivors would affect load perception and the severity of this impairment would correlate with gait symmetry.

2. Methods

2.1. Participants

Ten participants with chronic stroke were recruited to participate in this study (characteristics shown in Table 1). The mean age of the stroke participants was 57.27 years (standard deviation (S.D.) = 7.62 years). Two of the 10 stroke participants were female. All 10 participants had a cerebrovascular accident (CVA) more than 6 months before the test date. Due to the treadmill walking requirement of the test, we only recruited participants who were able to take steps independently. Participants were medically stable, with no concurrent medical illnesses. Participants were excluded for unhealed decubiti, bladder or other infection, severe contracture or osteoporosis, heterotopic ossification, cardiac arrhythmia or inability to give informed consent.

We also recruited 10 age-matched controls with no history of neurological disorder. The mean age of the age-matched controls was 57.42 years (S.D. = 8.25 years). Each control participant recruited in the study was within 3 years in age of one of the participants in the stroke group. The age of the stroke group and the age-matched control group was not significantly different ($p = 0.96$). There were 2 females in the age-matched control group. A third group of five young controls, mean age 25.88 years old (S.D. = 3.6795 years), were recruited into the study. In this group, all participants were female. Informed consent was obtained in writing from all participants before enrollment and participation in the study. All study procedures were conducted in accordance with the Declaration of Helsinki and with approval from the Northwestern University. All tests were conducted in research laboratories at the Rehabilitation Institute of Chicago (RIC).

2.2. Clinical measures

Clinical measures of sensory and motor function, and spasticity were measured in the stroke participants. The results are presented in Table 2. Sensory and motor function was measured using the Fugl-Meyer sensory and motor subtests for the lower extremities (Fugl-Meyer et al., 1975). Spasticity was assessed using the Modified Ashworth scale (Bohannon and Smith, 1987) on the ankle plantarflexors, knee flexors and extensors, and hip flexors, extensors and adductors.

Clinical observations suggest that a common barrier to successful walking is buckling at the knee, which affects the ability to support body weight during stance. Specifically, sufficient knee extension strength is needed to prevent knee buckling. Therefore, we assessed the isometric maximum voluntary contraction (MVC) torque for knee extension in the stroke group using the protocol described in previous studies (Hornby et al., 2009). Neckel and colleagues observed that the sagittal ankle and hip torques do not change during walking in stroke survivors; however, the sagittal knee torques differ significantly (Neckel et al., 2008). In order to examine strength in relation to walking, we compared the isometric knee torques to the maximum knee torque during normal walking as reported by Neckel et al. (2008). In normal walking, the highest knee extension torque occurs during early stance, and peaks at 0.3 Nm/kg. We normalized the maximum knee extension torque by each participant's body weight and all the stroke participants had a knee extension MVC that was higher than the knee extension torque needed during a gait cycle.

2.3. Experimental setup

An eight-camera motion capture system (Motion Analysis Corp, Santa Rosa, CA) was used to record three-dimensional movement of retroreflective markers placed on boney landmarks on both legs (Lewek et al., 2009). The 1 inch retroreflective markers were placed on the posterior sacrum, bilateral anterior–superior iliac spine, medial and lateral femoral condyles, medial and lateral malleoli, and posterior heel of the shoe and dorsally over the second and fifth metatarsal heads to identify the boney landmarks. Three