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Stance limb ground reaction forces in high functioning stroke and healthy subjects during gait initiation

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ABSTRACT

Background: Following stroke, little is known about ground reaction forces during gait initiation.
Objective: To compare stroke patients' with healthy subjects' anterior, medial, and lateral ground reaction forces generated during gait initiation.
Methods: Patients with left paresis, right paresis, and age-similar healthy subjects were recruited. During gait initiation the average peak anterior, medial, and lateral ground reaction forces acting on each lower limb were calculated when it was the stance limb.
Findings: Anterior ground reaction forces acting on the right and left stance limbs of healthy subjects were greater than anterior forces acting on the nonparetic and paretic limbs of stroke patients. Medial ground reaction forces for the nonparetic and paretic limbs of stroke patients and for the right and left stance limbs of healthy subjects were equivalent. While lateral ground reaction forces acting on the nonparetic and paretic limbs were equivalent for left paretic patients, for right paretic patients lateral forces acting on the nonparetic limb were *greater* compared to the paretic limb and also *greater* compared to the left limb of healthy subjects.
Interpretation: An effect of side-of-lesion was revealed in average peak lateral ground reaction force data. Larger lateral ground reaction forces acting on the left nonparetic stance limb of right paretic patients compared to the right nonparetic stance limb of left paretic patients during gait initiation may be an indication of differing adaptations that depend on the side-of-lesion.

1. Introduction

After stroke, most falls occur during transfers (Nyberg and Gustafson, 1995; Weerdesteyn et al., 2008). A transfer refers to the body transferring between two states of motion, such as during a sit-to-stand transfer, or during gait initiation (GI) when the body must switch from the task of quiet stance to dynamic movement. Despite this, little is known about how gait initiation is affected after stroke, and particularly whether ground reaction forces (GRFs) acting on the limbs during GI differ from healthy seniors in the anteroposterior and mediolateral axes.

It has previously been demonstrated that stroke patients generate smaller center of pressure (COP) trajectories with their paretic limb compared to healthy adult data (Hesse et al., 1997; Tokuno and Eng, 2006). However, few studies have demonstrated how GRFs are affected in the anteroposterior axis during GI after stroke (Tokuno and Eng, 2006; Brunt et al., 1995; Bensoussan et al., 2006). Further, only one of these studies has demonstrated how GRFs are affected in the mediolateral axis (Brunt et al., 1995). Mediolateral postural control in the elderly is a predictor of fall rate (Lord et al., 1999). Mediolateral postural control, in a task such as GI, and its relation to balance is likely an important topic to investigate in stroke patients. To achieve this, an understanding of the GRFs generated during GI is needed.

GI encompasses the time from a cue (external or internal) to stance limb toe-off (i.e., the second limb to step forward). Within the repertoire of lower limb activities, GI presents a particular challenge to the maintenance of postural stability. The human body acts as an inverted pendulum, with roughly 60% of the body mass, comprising the head, arms and trunk (HAT) segment, swinging over a pivot point at the ankle. During stationary standing, small postural changes to muscle activation are sufficient to maintain the COP within the base of support. During steady gait, pendulum dynamics are exploited to minimize the muscular effort required. GI represents a transition between these two conditions, in which GRFs are used to accelerate the COM from approximately stationary to its steady linear velocity in gait (Jian et al., 1993; Kuo, 2007). After stroke, this transition appears to be compromised (Hesse et al., 1997).

This study addresses the need to first characterize GRFs acting on the limbs during GI after stroke to begin to build an understanding of how hemiparesis might affect GI. Therefore anterior, medial, and lateral

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GRFs acting on the stance limb of stroke patients were recorded and compared with similar data recorded from a group of age-similar healthy subjects. Stance limb GRFs were chosen because the stance limb generates more propulsive forces than the swing limb during GI (Nissan and Whittle, 1990).

2. Methods

2.1. Subjects

Eighteen chronic stroke patients *(mean age 67.6 years, range 45–86)* and 28 age similar healthy subjects *(mean age 67.6, range 49–82)* were recruited for the study. The healthy group consisted of 14 men and 14 women. The stroke group consisted of nine patients with right hemisphere lesions (left paretic) and nine patients with left hemisphere lesions (right paretic) (see Table 1). No attempt was made to select patients by within-hemisphere lesion location. Patients with hemorrhagic and ischemic strokes were accepted. All patients experienced their stroke at least 6 months prior to participating in the study. Three groups of participants, healthy (Healthy), right paretic (RP) and left paretic (LP) participated in the GI protocol. Lower limb Fugl–Meyer (FM) assessments were conducted on patients. Stroke patients with moderate to high motor function were recruited to ensure they could meet experimental task requirements. Two right paretic patients wore ankle foot orthoses (AFOs). Participants were excluded if they had any known neurological conditions or impairments affecting their gait (other than stroke-related) e.g., a musculoskeletal disorders, recent knee replacement surgery, or leg injuries. The University of Auckland Human Participants Ethics Committee approved the study. The single session lasted about 1 h.

2.2. GI protocol

Participants stood at the end of a 6 m walkway in a comfortable and natural position with each foot on a separate force plate, wearing self-selected comfortable walking shoes. Subjects were asked to choose a natural starting position and this spot was marked on each force plate with visible tape so subjects could come back to this position for each trial. They were instructed to initiate gait at the sound of an auditory cue and continue walking from the force plates directly onto and along the walkway. Subjects were not instructed about speed. They self-selected their preferred speed. We acknowledge that self-selected foot position and step-off velocity may have added variability to the measures. However, gait initiation from an unfamiliar non-preferred foot position and constrained step-off velocity may also increase variability.

Left and right trials were collected in a random order and six trials were collected with each leg as the starting leg. Prior to the auditory cue that signaled the start of each trial, a verbal instruction was given to dictate whether to step forward with the right leg or left leg. For example, the researcher said 'Begin with your right leg'. The auditory cue to signal the initiation of gait was randomly delayed between 4 and 8 s following the verbal instruction. Force plate recordings were made from the time of auditory cue, through stance limb toe-off (when zero force was recorded from the force plate). This period, from cue to stance limb toe-off is defined as gait initiation in this study.

Table 1
Characteristics of stroke patients.

Subject #	Sex	Paretic side	Age	FM (of 34)
1	F	Left	83	33
2	M	Left	69	29
3	M	Left	77	32
4	M	Left	86	31
5	M	Left	79	33
6	M	Left	72	N/A
7	M	Left	70	34
8	M	Left	50	32
9	F	Left	58	32
Mean			71.6	32
10	M	Right	73	34
11	F	Right	68	30
12	M	Right	60	29
13	M	Right	49	26
14	M	Right	57	20
15	M	Right	45	21
16	M	Right	73	21
17	M	Right	75	34
18	M	Right	72	30
Mean			63.6	27.2

2.3. Ground reaction forces

GRFs were recorded from a Dual-Top Accusway force plate (AMTI, USA). The Dual-Top Accusway forceplate ($50 \times 50 \times 4.5$ cm) functions as two separate force plates. Data were collected from the start of the auditory cue for three seconds at a sampling rate of 50 Hz.

2.4. Clinical assessments

Experienced assessors conducted the motor function section of the lower limb FM impairment assessment (total score of 34) on stroke patients. A lower score indicated a greater level of impairment. One patient, whose FM score is represented as N/A (not applicable) in Table 1, did not undergo a FM assessment due to a bandaged wound on the top of the foot that prevented the Achilles reflex from being examined.

2.5. Data analysis

Trials were removed from analysis if participants failed to respond to the auditory cue or stepped forward with the non-specified limb. Each participant provided at least five correct trials for each stance limb. Peak anterior (Fy), medial (Fx-positive values), and lateral (Fx-negative values) GRFs were calculated for each stance limb. Raw data from representative participants are shown in Fig. 1. An estimate of body weight (BW) in N was obtained for each trial from the summed averages of the first 100 ms of vertical GRF (Fz) data collected by each force plate during quiet stance. The average of the first 100 ms of the vertical GRF of the stance limb was used to calculate initial limb loading, expressed as a percentage of body weight, by dividing the average vertical GRF of one force plate by the total vertical GRFs summed from both force plates. Peak GRFs in the three directions were expressed as a percentage of body weight for each trial. These normalized peak GRFs for each trial were then averaged across trials for the anterior, medial, and lateral directions for each individual.

To assess the effect of stroke on stance limb GRFs, LP and RP data were pooled into NP and P groups for separate analysis. For the healthy group, GRFs from the right and left lower limbs (R + L) were pooled.

To assess for side-of-lesion on GRFs acting on the stance limb in the three directions, GRFs for the right (R) and left (L) lower limbs of the Healthy, LP, and RP groups were analyzed separately.

2.6. Statistical analysis

One-way ANOVAs with post hoc Tukey's tests were used to detect an effect of limb (Healthy R + L, NP, P) on GRFs in the three directions. The three GRFs were then subjected to one-way ANOVAs with post hoc Tukey's tests for data pooled by limb (L, R) for the Healthy, LP, and RP groups to detect an effect of side-of-lesion.

Pairwise comparisons of R and L lower limb medial and lateral GRFs and comparisons of initial limb loading between the right NP and left NP limbs were conducted using one-tailed Student's t-tests. All data were