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The effect of arm movements on the lower limb during gait after a stroke

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ABSTRACT

The purpose of this study was to examine the influence of arm movements on lower limb movement and muscle activation during treadmill walking after a stroke. Ten high functioning stroke and 10 healthy subjects walked on a treadmill while swinging their arms naturally, and while holding onto handles that were either fixed in place or allowed to slide along horizontal handrails. Full-body kinematics were recorded, along with bilateral surface electromyography from lower limb muscles. Arm movements influenced lower limb muscle activity but had little effect on movement patterns at the joints. When handrails were present a small amount of weight was borne through the upper limbs, and for stroke subjects this was reduced when the handles were free to slide. Activity of proximal leg muscles during stance was affected by the weight borne through the upper limbs, increasing when arm movements were performed. Soleus activity during stance was greatest with unsupported arm movements. In stroke subjects, early stance tibialis anterior activity in the paretic leg was greatest with no arm movements, and early swing tibialis anterior activity in both legs was greatest with unsupported arm movements. Many of the changes in muscle activation appeared to be due to changes in postural stability that occurred when performing arm movements. Overall, results support further study of the long-term changes associated with the inclusion of arm movements in gait rehabilitation protocols.

1. Introduction

Human walking involves active movements of the upper limbs [1–3]. Constraining the arms influences the gait pattern in both healthy [4–6] and patient [7,8] populations, and there is indirect support for the existence of coupling between upper and lower limb muscular activation patterns [5,9]. Accordingly, upper limb involvement altered lower limb muscle activation during recumbent stepping movements in healthy individuals [10] and during passive reciprocal leg movement in individuals with spinal cord injury [11]. While there are anecdotal reports from spinal cord injured patients that stepping was facilitated [12] and patterns of lower limb muscle activity improved [13] when arm swing was performed during walking, this has not been systematically investigated.

One barrier to directly investigating the effects of arm movements on the lower limb during walking in patient populations is the ability of these individuals to walk safely without using their arms to hold on to fixed external devices for balance support. We fitted a treadmill with bilateral handles that could slide in the horizontal direction, allowing arm movements in the sagittal plane while still assisting with balance maintenance. When using the sliding handles, individuals who had sustained a stroke were able to incorporate arm movements into their gait pattern at faster speeds than they were otherwise able to do so [14]. This suggests that these handrails may have potential for use in gait rehabilitation, where speed is important [15], however a thorough understanding of their effect on the gait pattern is necessary before recommendations can be made.

The purpose of this study was to assess the influence of arm movements performed with and without the sliding handles on lower limb kinematic and muscle activation patterns during walking in individuals who have sustained a stroke. We hypothesized that performing arm movements during treadmill locomotion would result in stride characteristics and lower limb muscle activation in stroke patients that were more similar to those observed in healthy individuals.

2. Methods

2.1. Subjects

Ten individuals who had sustained a stroke (nine males; mean (SD) age 62 (10) years) participated in this study. Time since stroke ranged from 23 to 108 weeks. Detailed subject characteristics are provided in Stephenson et al. [14]. Data from 10 healthy adults (six males) of a similar age (62 (6) years) were used for comparison. The stroke subjects had incomplete motor recovery of the lower limb (Chedoke–McMaster

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Impairment Inventory [16] score <7/7 for the leg and foot) and sufficient ability to use the handrails (Chedoke–McMaster ≥3/7 for the arm and hand), and are the same subjects as those previously studied [14]. The project was approved by the institutional ethics committee and subjects provided free and informed consent prior to participation.

2.2. Equipment

The treadmill used was fitted with custom built sliding handles that were mounted with a low-friction bearing system on horizontal bars, allowing arm movements in the sagittal plane [14]. Handles were fitted with a load cell that was sensitive to force in the vertical direction (Omega, Stamford, CT). Subjects walked on the treadmill under three conditions: (1) holding onto handles that were fixed in place; (2) holding onto handles that were free to slide; and (3) not holding onto the handles and having the arms hang freely by the sides of the body. In condition 1 arm movements were prevented resulting in 'no arm movements'. In the other two conditions arm movements were encouraged, resulting in 'supported arm movements' in condition 2 and 'unsupported arm movements' in condition 3. The height and mediolateral location of the handrails were adjusted for each subject so that the position of the arms approximated that when they hung freely by the side of the body. All subjects wore a safety harness suspended from the ceiling that bore no weight but would provide support in the event of a fall.

2.3. Experimental procedure

The comfortable gait speed (CGS) of all subjects was measured using a self-paced capability of the treadmill, which allowed the subjects to modify gait speed at will [17]. The mean (SD) CGS of stroke subjects (0.68 (0.24) m s^{-1}) was slower than that of healthy subjects (1.19 (0.26) m s^{-1}). For nine stroke subjects CGS was measured with both no arm movements and supported arm movements, and did not differ between the two conditions (0.72 m s^{-1} *vs.* 0.69 m s^{-1}, $p = 0.422$). Treadmill speed was then controlled externally, as per a conventional treadmill, for all experimental trials. Stroke subjects performed trials at their pre-determined CGS. Healthy subjects performed trials at an assigned slow speed that matched the CGS of the stroke subjects (0.70 (0.23) m s^{-1}). A minimum of 10 strides was performed in every trial, and each condition was performed twice, resulting in 20 strides for analysis.

Kinematic data were sampled at 120 Hz with the Vicon-512 system (Vicon Peak, Oxford, UK), using forty reflective markers placed on specific anatomical landmarks (Vicon Plug-In-Gait). Muscle activation was recorded as surface electromyography (EMG) from the soleus, tibialis anterior, semitendinosus and quadriceps muscles on both sides of the body using a telemetric Telemyo900 system (Noraxon, AZ, USA). Although electrodes for the quadriceps were placed over the rectus femoris, the surface EMG recorded from this position is susceptible to cross talk from the vasti muscles [18]. These data are therefore interpreted as a more global representation of quadriceps activity. The skin over the muscle was rubbed with alcohol and a pair of 10 mm silver/silver chloride electrodes (Blue Sensor N-00-S, ABMU, Ølstykke, Denmark) was placed with 15 mm inter-electrode distance over the muscle. Surface EMG and the vertical forces exerted on the handles were sampled at 1080 Hz.

2.4. Data analysis

Joint angles were computed as the relative angle between adjacent segment vectors (Vicon Plug-In-Gait), and were low-pass filtered at 10 Hz using a dual-pass Butterworth filter (Matlab, MathWorks Inc., Natick, MA) for zero phase lag. Stride duration was defined as the time between two successive ipsilateral foot strikes. The range of motion (RoM) at the hip, knee and ankle was calculated for each stride as the peak-to-peak change in the angular displacement at these joints in the sagittal plane. Joint angle time series data were normalized to 100 points per stride and averaged over all 20 strides within a condition to obtain ensemble averaged joint angle profiles for each subject. These profiles were then averaged over all subjects within each group.

EMG signals were band-pass filtered (20–400 Hz), rectified, low-pass filtered (10 Hz) to generate a linear envelope, and normalized to 100 points per stride. Signal amplitude was normalized to the peak amplitude recorded with no arm movements. EMG data were quantified for each stride as the mean value of the normalized signal over pre-determined time-windows (Fig. 3) chosen to capture selected bursts of activity. These quantified values were averaged over all 20 strides within a given condition for each subject. Ensemble averaged EMG profiles were obtained in the same way as for kinematic data.

Due to technical issues, the force exerted on the handrails was recorded in only eight stroke subjects and six healthy subjects. Data were time normalized to 100 points per stride and amplitude was normalized to body weight. The mean force exerted was calculated over each 10% of the gait cycle.

After confirming the normality of the data (Shapiro–Wilks test), a two-way analysis of variance (ANOVA) of Condition (no *vs.* supported *vs.* unsupported arm movements) × Side (left *vs.* right or paretic *vs.* non-paretic), with repeated measures on both factors, was performed for each group of subjects. There were no differences in any variables between the left and right side of the healthy subjects and data from the left side was used for comparisons across groups. A two-way ANOVA of Group (stroke *vs.* healthy) × Condition, with repeated measures on Condition, was performed once to compare the paretic side of stroke subjects to healthy subjects, and again to compare the non-paretic side of stroke subjects to healthy subjects. When the ANOVA yielded a significant interaction ($p < 0.05$), post hoc analyses were completed using *t*-tests with Bonferonni correction for multiple comparisons. Statistical analyses were performed using SPSS™ and Statistica™ software.

3. Results

3.1. Lower limb kinematics

Both groups of subjects took more frequent and shorter strides when performing unsupported arm movements (Fig. 1). There was a significant main effect of arm movement condition for ankle RoM in stroke ($p = 0.029$) and healthy ($p = 0.012$) subjects (Fig. 2). Although no post hoc comparisons were significant the tendency was for reduced ankle RoM with unsupported arm movements. Knee RoM did not differ with arm movement condition, and hip RoM was lowest with unsupported arm movements for both groups of subjects. The changes in ankle and hip RoM are likely to be related to the reduced stride length observed with unsupported arm movements.

3.2. Lower limb muscle activity

Ensemble averaged EMG profiles are shown in Fig. 3. In stroke subjects, early stance quadriceps activity was larger with

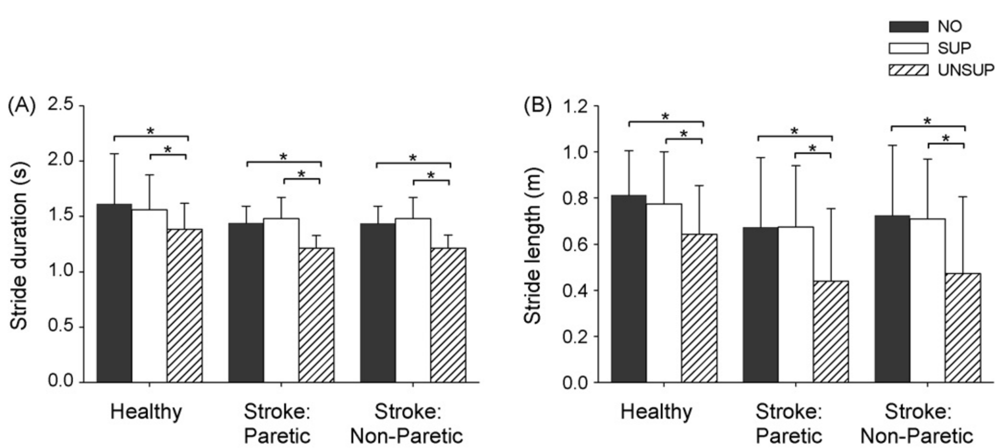

Fig. 1. Stride duration (A) and stride length (B) during walking with no arm movements (NO), while performing supported arm movements using sliding handrails (SUP) and while performing unsupported arm movements (UNSUP). Data are shown for the paretic and non-paretic sides of stroke subjects walking at comfortable speed, and for the left side of healthy subjects walking at a matched speed. Error bars represent +1SD. Significant ($p < 0.05$) differences between arm movement conditions are indicated with asterisks (*).