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Impact of stroke on anterior–posterior force generation prior to seat-off during sit-to-walk

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ABSTRACT

Force generation during sit-to-walk (STW) post-stroke is a poorly studied area, although STW is a common daily transfer giving rise to a risk of falling in persons with disability. The purpose of this study was to describe and compare strategies for anterior–posterior (AP) force generation prior to seat-off during the STW transfer in both subjects with stroke and in matched controls.

During STW at self-selected speed, AP force data were collected by 4 force plates, beneath the buttocks and feet from eight subjects with stroke (>6 months after onset) and 8 matched controls.

Subjects with post-stroke hemiparesis and matched controls generated a similar magnitude of total AP force impulses ($F_{1,71} = 0.67$; $p = 0.42$) beneath buttocks and feet prior to seat-off during STW. However, there were significant group differences in AP force impulse generation beneath the stance buttock (i.e. the non-paretic buttock in the stroke group), with longer duration ($F_{1,71} = 8.78$; $p < 0.005$), larger net AP impulse ($F_{1,71} = 6.76$; $p < 0.05$) and larger braking impulse ($F_{1,71} = 7.24$; $p < 0.05$) in the stroke group. The total braking impulse beneath buttocks and feet was about 4.5 times larger in the stroke group than in the control group ($F_{1,71} = 8.84$; $p < 0.005$).

An intra- and inter-limb dys-coordination with substantial use of braking impulses was demonstrated in the stroke group. This motor strategy differed markedly from the smooth force interaction in the control group. These results might be important in the development of treatment models related to locomotion post-stroke.

1. Introduction

Gait initiated from sitting, i.e. sit-to-walk (STW), is a frequently performed transfer, with an asymmetry embedded in the task. Typically, the forthcoming swing leg leaves the ground before the body is fully extended [1]. This asymmetry is challenging, from both locomotor and equilibrium perspectives, and possibly even more so in subjects with hemiparesis after stroke.

The STW transfer has been investigated in young [1,2] and old [3,4] adults as well as in subjects with Parkinson's disease [5] and stroke [6–8]. The development, testing, and use of a clinical assessment tool, the Fluidity Scale, is documented [6,7] and events and phases are suggested and defined for the STW transfer in subjects with stroke and in matched controls [8]. Group differences in relative phase duration was found in the proposed second STW phase, defined as lasting from seat-off to the loading peak of the forthcoming swing leg [8], which may be attributable to reduced force generation before rising in subjects with stroke. However, there is a lack of information on force parameters regulating STW motor performance post-stroke.

Although kinetic information on the STW transfer in subjects with post-stroke hemiparesis is lacking, force contribution from the paretic and non-paretic leg during other daily tasks is reported. During quiet standing [9,10] and when platform perturbations are induced [11], the non-paretic leg is the predominant contributor to lateralised postural control. Throughout the process of sit-to-stand and stand-to-sit, subjects with hemiparesis present varying degrees

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of asymmetry in vertical limb-loading [12]. During gait initiation from standing, subjects with post-stroke and with initial symmetrical limb loading generate propulsion through the paretic swing leg whereas, with asymmetrical limb loading a braking impulse is exerted by the paretic leg [13].

During walking, Bowden et al. [14] explored anterior–posterior (AP) ground reaction forces in 47 subjects with stroke and suggested a measure to quantify the percentage contribution from the paretic leg to total propulsion (Pp) that correlates with gait speed and degree of paresis. Later, the Pp-measure was tested in another study of walking post-stroke, and a strong negative correlation was found with step length asymmetry [15].

To our knowledge, there is no information about the impact of stroke on AP force generation during STW, even though this is a frequently performed transfer. Further, in subjects with post-stroke hemiparesis there is an increased risk for falls and everyday transfers constitute one situation where falls can occur [16].

The hypothesis for this study was that subjects with post-stroke hemiparesis would generate less AP forces beneath buttocks and feet prior to seat-off during the STW transfer than control subjects. Therefore, the purpose of the study was to describe and compare strategies for AP force generation prior to seat-off during the STW transfer in subjects with stroke and in controls.

2. Methods

2.1. Participants

Eight subjects with stroke (4 females and 4 males; mean age 60 years (±6.1)) and eight controls (mean age 61 years (±3.1)), matched for gender, age, height, weight and body mass index (subjects with stroke 26.7 kg/m^2 (±4.5); controls 26.8 kg/m^2 (±3.4)) were enrolled into the study. All subjects were recruited through convenience sampling. The subjects with stroke had sustained brain infarction ($n = 3$) or haemorrhage ($n = 5$) between 9 and 72 months (mean 49 months) prior to the study.

The participants were able to rise from sitting and walk a short distance independently, without a walking aid. Exclusion criteria included cardiovascular, orthopaedic or any neurological disorder (other than stroke) that might impair locomotion. The walking capacity of the subjects with stroke varied, as demonstrated by gait velocities ranging from 0.57 to 1.27 m/s. The data collection was part of a larger study, including older persons with fear of falling, thus the General Motor Function Scale [17] was used to characterise all subjects' function-related dependence, pain and insecurity during daily activities. Two of the subjects with stroke used a cane when walking outdoors, and five had difficulty in managing stairs without handrails. Seven of the eight subjects with stroke moved independently outdoors. Informed consent, in accordance with guidelines, was obtained from all subjects before data collection and the local ethics committee of the medical faculty approved the study.

2.2. Procedure and data collection

The experiment was designed to resemble the daily activity of rising and walking to answer the telephone. The subject, seated on a platform at a standard height of 0.45 m, was instructed to walk comfortably forward to a telephone, after hearing an auditory signal. There was no standardised foot position, and the subject could use upper extremities and decide which leg to use as first swing leg.

Four AMTI force plates (Advanced Mechanical Technology Inc.; model MC818-16-100; size 457 × 203 mm), positioned beneath each buttock on the platform and beneath each foot (embedded in a 5.0 m long and 1.2 m broad walkway) collected 3D kinetic data at a frequency of 100 Hz. An 8-camera movement analysis system (ELITE, BTS) collected 3D kinematic data at a frequency of 100 Hz. Information from 38 markers, representing 13 body segments, was used to define STW-onset [8]. Kinetic and kinematic signals were recorded synchronously during baseline (about 3 s) as well as during the performance of the STW transfer. Each subject performed a total of 10 STW trials. A detailed description of the set-up is published elsewhere [8].

2.3. Data analyses

For further processing, data from the six central trials of 10 performed were chosen to avoid learning effects and fatigue. The whole body's centre of mass (COM), its velocity and momentum, were calculated from the position of each body segment, obtained from the marker data. STW-onset was defined [8] as the instant when COM horizontal momentum exceeded a threshold of 7% of the value of its peak [18] prior to seat-off. Force data were filtered by a low-pass filter (Butterworth, fourth order, zero-phase) with 10 Hz cut-off frequency and normalised to body weight. Anterior–posterior force data from the four force plates were processed through cursor read-outs and force impulses were calculated by AxoGraph software (Axon Instruments Inc.).

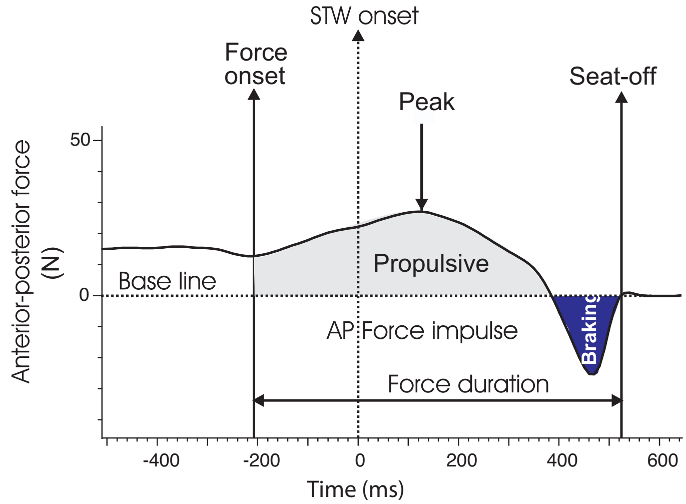

Fig. 1. Description of variables of anterior–posterior (AP) force impulse being generated prior to seat-off during sit-to-walk (STW), including propulsive (positive going trace indicating forward directed ground reaction force) and braking (negative going trace indicating backward directed ground reaction force) components. Note: AP forces generated prior to seat-off include both force generation before STW onset and during the first STW-phase (defined as lasting from the instant when COM horizontal momentum exceeds a threshold of 7% of the value of its peak [18], at the beginning of STW, to seat-off). The graph is derived from the paretic swing buttock in one STW trial of a subject with stroke.

The focus of the present study was on the generation of AP forces starting prior to STW-onset and during the first STW phase [8], ending at seat-off. Force onset was determined as the first observable continuous increase in AP force traces (Fig. 1). Force duration was measured as the time between force onset and seat-off. The net AP force impulses from each buttock and foot, including propulsive and braking components, were calculated. Finally, total AP forces and total braking impulses from the buttocks and feet were computed. Timing, in relation to seat-off, and magnitude of AP impulse peaks generated from the buttocks were processed.

2.4. Statistical analyses

Two subjects with post-stroke hemiparesis initiated gait with their non-paretic leg in two out of six trials; thus, in the stroke group gait was initiated with the non-paretic leg in four out of 48 trials. These trials, and the matched trials of the controls, were excluded from the statistical analyses. All control subjects initiated gait with the same leg in all analysed STW-trials. Thus, the following evaluation comprised eight subjects with stroke that used their paretic leg as first swing leg (44 trials) in combination with eight control subjects (44 trials); 88 STW-trials in total.

In statistical terms, the primary object of the study was to infer whether stroke has an effect on STW-performance, i.e. on the expected value of the selected variables. This was done by assigning control subjects to subjects with stroke on a matched-pair basis. In order to estimate the measures of uncertainty, the hypotheses tests were conditioned with respect to the covariance structures assumed within both matched pairs and within individual subjects. Such conditioned tests were achieved with a mixed model ANOVA (STATISTICA ver. 8.0, Stat Soft Inc.), where the respective indices of matched pairs and subjects were used as random factors together with group as a fixed factor. Restricted maximum likelihood estimates were calculated [19] and used to produce the asymptotic prob-values (p) and the corresponding F-statistics.

3. Results

An example of AP force impulse generation prior to seat-off during STW from a single trial in a subject with stroke and the matched control is presented in Fig. 2. Timing and scaling of the AP force generation for the respective stroke and control groups are displayed in Fig. 3 and reported in Table 1.

3.1. Temporal characteristics

There was no difference within or between the groups in onset of AP force impulse generation beneath the buttocks prior to