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ORIGINAL ARTICLE

Interlimb Coordination During the Stance Phase of Gait in Subjects With Stroke

Andreia S.P. Sousa, PhD,[a,b] Augusta Silva, PhD,[a] Rubim Santos, PhD,[a] Filipa Sousa, PhD,[c] João Manuel R.S. Tavares, PhD[d]

From the [a]Escola Superior da Tecnologia de Saúde do Instituto Politécnico do Porto, Área Científica de Fisioterapia, Centro de Estudos de Movimento e Actividade Humana, Vila Nova de Gaia; [b]Faculdade de Engenharia, Universidade do Porto, Porto; [c]Laboratório de Biomecânica do Porto, Faculdade de Desporto, Universidade do Porto, Porto; and [d]Instituto de Engenharia Mecânica e Gestão Industrial, Departamento de Engenharia Mecânica, Faculdade de Engenharia, Universidade do Porto, Porto, Portugal.

Abstract

Objective: To analyze the relation between contralesional and ipsilesional limbs in subjects with stroke during step-to-step transition of walking.

Design: Observational, transversal, analytical study with a convenience sample.

Setting: Physical medicine and rehabilitation clinic.

Participants: Subjects ($n=16$) with poststroke hemiparesis with the ability to walk independently and healthy controls ($n=22$).

Interventions: Not applicable.

Main Outcome Measures: Bilateral lower limbs electromyographic activity of the soleus (SOL), gastrocnemius medialis, tibialis anterior, biceps femoris, rectus femoris, and vastus medialis (VM) muscles and the ground reaction force were analyzed during double-support and terminal stance phases of gait.

Results: The propulsive impulse of the contralesional trailing limb was negatively correlated with the braking impulse of the leading limb during double support ($r=-.639$, $P=.01$). A moderate functional relation was observed between thigh muscles ($r=-.529$, $P=.035$), and a strong and moderate dysfunctional relation was found between the plantar flexors of the ipsilesional limb and the vastus medialis of the contralesional limb, respectively (SOL-VM, $r=-.80$, $P<.001$; gastrocnemius medialis-VM, $r=-.655$, $P=.002$). Also, a functional moderate negative correlation was found between the SOL and rectus femoris muscles of the ipsilesional limb during terminal stance and between the SOL ($r=-.506$, $P=.046$) and VM ($r=-.518$, $P=.04$) muscles of the contralesional limb during loading response, respectively. The trailing limb relative impulse contribution of the contralesional limb was lower than the ipsilesional limb of subjects with stroke ($P=.02$) and lower than the relative impulse contribution of the healthy limb ($P=.008$) during double support.

Conclusions: The findings obtained suggest that the lower performance of the contralesional limb in forward propulsion during gait is related not only to contralateral supraspinal damage but also to a dysfunctional influence of the ipsilesional limb.

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Gait disorders affect a large proportion of subjects with stroke, limiting their ability to ambulate in the community.[1] The features of poststroke walking vary according to stroke severity, location of infarct, time since stroke, type of rehabilitation received, and other individual differences.[2] Also, the mechanical energy cost per stride and metabolic energy expenditure[3] are typically higher in subjects with stroke than healthy subjects.

Biomechanical models have shown the importance of interlimb relations during the double-support phase in unimpaired gait energy consumption.[4] The transition from one stance limb inverted pendulum to the next appears to be a major determinant of the mechanical work of walking.[4,5] An optimal mechanical relation between human limbs, described as the trailing limb plantar flexor action,[6,7] compensates the energy loss provoked by the leading limb during heel strike[5,8] to maintain the velocity of the body's

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center of mass. Recent studies involving healthy subjects have demonstrated that the degree of plantar flexor activity during propulsion depends on the degree of muscle activity[9] and the magnitude of the ground reaction force[10] of the contralateral limb during heel strike. This interlimb relation observed during step-to-step transition of unimpaired walking,[9,10] and also in standing-related tasks,[11,12] can be justified by the bilateral influence of group II fibers on spinal interneurons[13] and the importance of vestibulo- and reticulospinal pathways on group II fibers.[14]

After a unilateral stroke, interlimb coordination is often impaired[15-17] as a result of the primary brain lesion itself and/or adaptive changes.[18-21] Although studies about interlimb relations have been dedicated to the evaluation of upper limbs, neurophysiological and neuroanatomic findings indicate that the interlimb coordination of lower limbs can be impaired, particularly when there are subcortical injuries in the territory of the middle cerebral artery, such as in the internal capsule.[22,23]

Subjects with stroke present low kinetic energy[24,25] and an inadequate propulsion of the contralateral limb to the affected hemisphere (contralesional limb) during preswing[26] as a result of low plantar flexor strength and power.[2,27] The major metabolic cost has been associated with the mechanical work done by the ipsilesional limb, mainly to lift the center of mass.[28] However, in spite of often being described as a compensatory limb that adapts to changes in the paretic limb,[29] changes observed in the ipsilesional limb have also been attributed to a possible dysfunction of ipsilateral distributed pathways responsible for postural control.[29-33] This could help us to understand why stroke subjects present lower performance of the contralesional limb when cyclic and antiphase ankle movements are executed with both limbs.[34,35] In fact, these findings suggest that the ipsilesional limb may lead to performance changes in the contralesional limb and reinforce the idea that step-to-step transition during gait could be highly demanding in terms of energy consumption in stroke subjects because of their need to coordinate contralesional and ipsilesional limbs.

The main purpose of this study was to analyze the relation between ipsilesional and contralesional limbs during gait step-to-step transition in terms of individual muscle activity and global kinetic values in subjects with stroke. Taking into account the changes observed in both contralesional[26,27] and ipsilesional[30] limbs during gait, a dysfunctional interlimb relation was hypothesized compared with interlimb relation patterns observed in healthy subjects.[9] Specifically, a higher dysfunctional relation would be expected between the ipsilesional heel strike limb and the contralesional propulsion limb. This hypothesis is based on the role of the ipsilateral and contralateral pathways because the former is more related to postural control, highlighted in the moment of touchdown, and the latter is more associated with movement control, highlighted during propulsion.[22]

To our knowledge, no previous study has evaluated the interlimb relation during an asymmetric task, implying a supportive role for the 2 limbs in subjects with stroke. Whereas correlation analyses have revealed that some electromyographic abnormalities, such as spasticity,[36] altered cocontraction,[37] and muscle paresis,[29] are higher in subjects with severe stroke, a cause-effect relation of some of these abnormalities with poor locomotor performance[3] remains difficult to establish. The study of interlimb relations during step-to-step transition in subjects with stroke can give significant insights to improve our understanding of the low performance of stroke gait, considering the importance of step-to-step transition performance in global gait efficiency. Restoring gait is one of the major goals in stroke rehabilitation; therefore, understanding the interlimb relation is extremely beneficial for designing effective locomotor interventions.

List of abbreviations:

BF biceps femoris
GM gastrocnemius medialis
RF rectus femoris
SOL soleus
TA tibialis anterior
VM vastus medialis

Methods

Participants

Sixteen (8 women, 8 men) patients who had suffered a stroke at least 6 months earlier and 22 healthy subjects (12 women, 10 men) participated in this study (table 1). For the subjects with stroke, the mean time ± SD between their stroke and the time of inclusion was 26±9 months. All subjects suffered an ischemic stroke: 11 of them had suffered an infarction in their left hemisphere, whereas 5 had suffered an infarction in their right hemisphere. To be included, patients were required to (1) have suffered an ischemic first-ever stroke involving the territory of the middle cerebral artery, as revealed by computed tomography, resulting in hemiparesis; (2) have a Fugl-Meyer Assessment of Sensorimotor Recovery After Stroke scale score in the motor subsection <34; (3) have the ability to walk 10m, with close supervision if necessary, but without physical assistance, as judged by the treating physiotherapist; and (4) have provided written or verbal informed consent. Patients were excluded for one of the following reasons: (1) cognitive deficit that could hinder communication and cooperation (assessed by the Mini-Mental State Examination); (2) history of orthopedic or neurologic (other than stroke) disorders known to affect walking performance; (3) history of stroke involving the brainstem or cerebellar areas; and (4) taking medication that could affect motor performance. Given the possibility of spastic hypertonus, an experienced neurologic physical therapist (A.F.S.) assessed all subjects by testing limb resistance to passive movement; considering the definition of spastic hypertonus, all subjects included in the study were considered as not having spastic hypertonus in the lower extremity. Gait data of the group of subjects with stroke were compared with data obtained from the 22 healthy control subjects. All control group subjects were sedentary and were selected according to the same exclusion criteria applied to the stroke group and were also excluded if they

Table 1 Mean ± SD values of age, height, and weight of the healthy and stroke groups and the average values of the self-selected walking speeds adopted by each group

Variables	Stroke Group	Control Group	*P*
Age (y)	53.87±7.17	49.24±7.69	.070
Height (m)	1.65±0.10	1.66±0.09	.942
Body weight (kg)	75.29±7.03	67.40±8.76	.006
Self-selected gait speed ($m \cdot s^{-1}$)	0.57±0.13	1.00±0.03	<.001

NOTE. Values are mean ± SD or as otherwise indicated.