PENDULAR ENERGY TRANSDUCTION WITHIN STEP IN STROKE SUBJECTS IS DEPENDENT OF WALKING SPEED

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SUMMARY
Results indicated that stroke group showed higher vertical Body Center Of Mass (BCM) oscillation and lesser BCM forward kinetic mechanical energy (E_ki(t)) oscillation, as expected. Furthermore, stroke group showed ~11% higher energy recovery within step (R_ext) with the affected lower limb at slow speeds of walking (p=0.047) and ~10% higher R_ext with the unaffected lower limb at higher speeds of walking (p=0.045). These results provide insights to a better understanding of how mechanical energy and energy recovery affects gait in stroke patients and allows develop new therapeutic and physical interventions, such as, biofeedback instrumented treadmills for gait training.

INTRODUCTION
Ischemic stroke results from reduction in cerebral blood flow and triggers a cascade of biochemical events such as glutamatergic excitotoxicity, peri-infarct depolarizations, inflammation and programmed cell death [1]. This upper motor neuron injury remains the third leading cause of death in development countries [2]. After the ischemic episode around 80% of survivors live with some kind of sensory motor inability and generally a hemiparetic gait pattern appears. The main clinical features of stroke are motor impairments, such as, paresis, excessive muscle co-activation and spasticity, as well as changes in passive properties of muscles [3, 4]. Besides, abnormal kinematic patterns cause decreased range of motion and, consequently, reduction of walking speed [5, 6]. These neurological impairments lead to an increase in metabolic energy cost during walking. An essential question to the functionality in locomotion relates to total energy cost for this activity. Modifications in mechanics influence energy cost of locomotion. Minimization of energy expenditure has long been considered a fundamental characteristic of walking. This line of reasoning has led researchers to examine mechanism of energy conservation in persons with walking disabilities [7]. Human locomotion, when analyzed by BCM displacement, is influenced by two mechanical energies: gravitational potential energy (E_p) and kinetic energy (E_k) [8, 9]. The objective of this study was to compare mechanical energy and energy recovery between healthy and stroke subjects. This understanding has clinical implications for therapies aiming to improve walking economy in patients with gait disorders that affect center of mass displacement and metabolic cost [11].

METHODS
Study population

Six chronic hemiparetic post-stroke patients (5 men and 1 woman, mean age: 63±11 years, mean height: 168±8 cm, mean weight: 79±10 kg) were recruited from rehabilitation units situated in Porto Alegre, Brazil between March and December 2010. Ten healthy age-matched subjects (six men and four women; mean age: 58±7 years, mean height: 168±7 cm, mean weight: 72±6 kg) were also evaluated and served as control group. Patients were able to walk independently and scored 100% for the Barthel Index [12]. Stroke patients were also evaluated by Ashworth scale and they scored 1. They were also able to walk on a treadmill for sufficient time to complete mechanical and metabolic analysis and had no other major medical disorders. International Physical Activity Questionnaire (IPAQ) was used to pair healthy subjects and patients about the level of physical activity [13]. This study was approved by the institutional ethics committee and all participants were made aware of potential risks before signing an informed consent form.

Experimental protocol
Measurements were made whilst participants walked on a motor-driven treadmill (BH fitness Explorer ProAction) at five different speeds: preferred walking speed (PWS); two speeds above PWS (1PWS and 2PWS) and two speeds below PWS (-1PWS and -2PWS), randomly. For control group the PWS was 3.0 km.h\(^{-1}\) and for stroke group was 2.3 km.h\(^{-1}\). Based on studies that assess pathological locomotion, hemiparetic subjects show limitation at the walking speed, which is between 1.9-3.6 km.h\(^{-1}\) [5, 14]. So, PWS increment or decrement were encompassed in this range, thus the speed of walking ranged between 1.3-3.3 km.h\(^{-1}\) for the stroke group and for the control group the speed ranged between 1.4-2.0 km.h\(^{-1}\).

Mechanical energy and pendular energy transduction within step
Gait was assessed by three-dimensional (3D) analysis. Segmental kinematics were measured with a four-camera system (JVC GY-DVL 9800 – JVC Company of America, Wayne, New Jersey, USA; sampling rate of 50 Hz for 60s). Eighteen reflective markers (15 mm diameter) were attached bilaterally to landmarks which defined segment extremities: immediately anterior to tragus of ear, shoulder, elbow, wrist, greater trochanter, lateral epicondyle of femur, lateral malleolus, calcaneous, and 5\(^{th}\) metatarsal head [15, 16]. Data were filtered with low-pass, fourth-order Butterworth filter and the cutoff frequency was determined by residual analysis of Winter [17]. Anthropometric data of 11 rigid segments (head-trunk, upper arms, lower arms, thighs, shanks, feet) were used to compute position of the segments and BCM [18, 19]. Linear and angular velocity of each segment and linear velocity of BCM was determined by mathematical derivative. Computational algorithms were constructed to calculate the mechanical energy and R_ext using Labview\(^{®}\) (version 8.5, National Instruments, Austin, USA), as follows:

\[
E_{\text{ext}}(t) = \frac{1}{2} M v_f(t)^2 + \frac{1}{2} M v_y(t)^2 + M g y(t)
\]

(1) [20]

Where \(M\) is body mass in kg, \(v_f\) is the forward velocity of BCM in m.s\(^{-1}\), \(v_y\) is vertical velocity of BCM in m.s\(^{-1}\), \(g\) is acceleration due to gravity (9.81 m.s\(^{-2}\)) and \(y\) is vertical position of BCM. The first term of the equation is the forward kinetic mechanical energy (E_kf), second term is the vertical kinetic mechanical energy (E_v) and the third part is the potential mechanical energy (E_p), which in sum is the external mechanical energy (E_{ext}) [20].

\[
r(t) = 1 - \frac{E_{\text{ext}}(t)}{E_{\text{ext}}(t) + E_{\text{int}}(t)}
\]

(2) [20]

Where \(E_{\text{ext}}(t)\) is the external mechanical energy (i.e., \(E_p + E_k\)) at instant of time \(t\) in Joules, \(E_{\text{int}}(t)\) is the potential mechanical energy at instant of time \(t\)
RESULTS AND DISCUSSION

E\textsubscript{p} oscillation was higher in stroke group by an average of \(-45\%\) (Fig. 1a and 1b). Stoke gait shows higher vertical displacements of BCM [14] and a flattened panner of the E\textsubscript{sh} [5, 14]. In addiction there was a significant higher R\textsubscript{int} for stroke group at 50\% of gait cycle (p=0.047) at -2PWS and a higher R\textsubscript{int} at 100\% of gait cycle (p=0.045) at 2PWS. At -1PWS, PWS and 1PWS control group had higher R\textsubscript{int} at all comparisons (data not shown). This study is the first to calculate R\textsubscript{int} for stroke subjects. This method is important because it is possible to understand at which \% of gait cycle stroke subjects have more or less mechanical energy recovery. In the past, stroke gait energy recovery was analyzed [5], as a result these authors found less energy recovery for stroke subjects when compared to control group, but only the PWS and usual energy recovery calculation were employed. In this study we analyzed 5 different speeds and with a new method of calculation [20]. Thus, it was possible to notice differences which could not be seen in the past. The results of this study showed a higher R\textsubscript{int} at 50\% of gait cycle (-2PWS; Figure 1c), so at slow speeds stroke subjects are using the affected lower limb to optimize pendular transduction [20]. Furthermore, at 2PWS stroke group had higher R\textsubscript{int} at 100\% of gait cycle, with an optimization for energy recovery with unaffected side.

CONCLUSIONS

Considerable differences were found in R\textsubscript{int} between control group and stroke group by means of this method proposed by Cavagna et al. (2002) [20]. These differences which once were not detectable appeared. Besides lesser R\textsubscript{int} at intermediate speeds (-1PWS, PWS, and 1PWS; data not shown) stroke subjects performed (i) \(\approx11\%\) higher R\textsubscript{int} with the affected lower limb at slow speeds of walking (p=0.047) and (ii) \(\approx10\%\) higher R\textsubscript{int} with the unaffacted lower limb at higher speeds of walking (p=0.045). In the first case, it is possible that the stroke group had developed a neuromuscular strategy to overcome the functional deficits due to hemiparesis, using the affected limb optimized for pendular transduction, overcoming the functional deficits due to partial loss of muscle strength. By this means stroke group could be more efficient, even without the muscle power to do it. And, in the second case, our research group verified increased gait symmetry for the stroke group at higher speeds, and this could explain the higher energy recovery at such speed (data not published). These results allows verifying the efficacy of and to develop new therapeutic interventions for stroke treatment.

REFERENCES