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# Muscular utilization of the plantarflexors, hip flexors and extensors in persons with hemiparesis walking at self-selected and maximal speeds

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**Abstract**

Gait performance secondary to a stroke is partially dependent on residual muscle strength. However, to pinpoint more precisely the mechanism of this relationship, biomechanical models, such as the muscular utilization ratio (MUR) that integrates both muscle strength and gait parameters into the concept of level of effort, are warranted. The aim of the present study was to evaluate the MUR of plantarflexors, hip flexors and extensor muscles during their concentric action in 17 chronic hemiparetic participants walking at self-selected and maximal speeds. Results revealed that peak MUR increased with gait speed. At self-selected speed ($0.73 \pm 0.27$ m/s), peak MUR values on the paretic side were 64% (±18.7), 46% (±27.6) and 33% (±25.6) for the plantarflexors, hip flexors and extensor muscles, respectively. At maximal speed ($1.26 \pm 0.39$ m/s), corresponding values were 77% (±23.6), 72% (±33.0) and 58% (±32.1). Peak MUR showed negative associations ($-0.33 < r > -0.68$), although not all significant, with voluntary muscle strength. The results of this study indicated that the peak MUR increased with gait speed. The plantarflexors were the most used muscle group at self-selected speed, whereas at maximal speed the three muscle groups showed similar peak MUR values. This last finding suggested an important role of the hip muscles in reaching a faster speed. Lastly, because moderate associations were found between peak MUR values and the voluntary muscle strength of hip flexors and extensors, it can be concluded that the weakest paretic muscle groups show, in general, the highest level of effort during gait.


*Keywords:* Gait; Strength; Energy generation; Effort; Stroke; Rehabilitation

## 1. Introduction

Stroke can lead to several deficits affecting survivors. Among these, gait disturbance has been extensively studied because recovery represents a major goal for clinicians and patients [8]. Gait speed is an indicator often used in research aiming to highlight gait deficiency in persons with hemiparesis [6,20,29,35]. Studies have reported a variable decrease in gait speed with mean values as low as 0.23 m/s. In some studies, the self-selected gait speed of hemiparetic individuals corresponded to the slow speed of healthy participants [9,13,45,47].

Several factors such as sensation and balance influence gait speed following a stroke [6,9,20,29], but one of the major determinants is residual strength on the paretic side. Indeed, many studies have found a significant association, although of variable magnitude, between the residual strength of several muscle groups of the lower limb evaluated on a dynamometer and the gait speed of persons with hemiparesis [5,7,12,20,29,32]. Even if correlation relates these two variables, it cannot give an insight into the intrinsic mechanism by which hemiparetic individuals use their strength during walking. For example, because muscle fatigue [46] and effort [21] are related to the percentage of the

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maximal capacity of muscles used in a task, it could be hypothesized that some hemiparetic individuals could try to minimize muscle fatigue or effort during gait by using an appropriate percentage of their maximal strength. By slowing gait speed, these individuals could reduce the joint moments needed for gait progression and thus could use lower percentages of their maximal strength. An alternative hypothesis could be that residual strength represents a limiting factor for gait speed in individuals using all the available strength of a particular muscle group. In that case, the moment generated by the muscle group during gait should be equal to the maximal torque recorded in a dynamometric evaluation. It is apparent that correlation methods alone cannot specify which of the previous mechanisms apply.

One way to look more precisely at the link between strength and walking performance secondary to a stroke is to determine the muscular utilization ratio (MUR). The MUR provides an index of the percentage of maximal strength used by a given muscle group during a task such as gait (for more details see [31]). In a recent study of healthy individuals walking at four cadences (60, 80, self-selected and 120 steps/min), Requiao et al. [41] reported mean values of peak MUR (both sides averaged) for the self-selected speed of 60.8%, 43.0% and 35.3% for the plantarflexors, hip flexors and hip extensors, respectively. They also demonstrated that hip muscles showed the largest change with cadence, reaching the MUR of plantarflexors at the fastest cadence (120 steps/min).

In the hemiparetic population, Nadeau et al. [32] estimated the MUR of plantarflexors during their concentric action at the push-off phase. They reported average values of peak MUR at self-selected and maximal speeds of $76.4 \pm 34.7\%$ and $85.9 \pm 31.9\%$, respectively. As speed increased, more strength was required by the plantarflexors to propel the leg forward. However, the authors mentioned that, even though the weakest participants tended to be limited by the strength of their plantarflexors at maximal speed, some were still able to walk rapidly, reaching the speed values of participants considered not limited by weakness of the plantarflexors. Looking at the correlation between gait speed and hip flexor strength produced on the dynamometer ($r = 0.84$; $p < .05$) and the correlation between gait speed and the net joint moment in hip flexion during maximal speed ($r = 0.57$; $p < .05$), Nadeau et al. [32] suggested that hip flexors probably compensated for plantarflexor weakness to allow an increase in gait speed. Other authors endorsed the role of compensation in hemiparetic gait by examining the large burst of power produced by the hip muscles in fast-walking hemiparetic individuals presenting diminished capability of ankle plantarflexors [36]. These findings further supported the idea of the role of compensation between muscle groups during gait as previously suggested for individuals having other physical impairments [27,28].

Considering that gait speed influences the peak MUR of various muscle groups and that complex compensations between muscle groups are expected in hemiparetic gait, it is relevant to evaluate MUR in all muscle groups sharing a common function. Gait speed is largely regulated by the activity of the plantarflexors, hip flexors and hip extensor muscles. The concentric action of these muscle groups gives rise to the generation of energy to ensure the forward displacement of the body [50]. It is well recognized that the main energy generation phases of these muscles are disturbed secondary to a stroke [39].

The aim of the present study was therefore to estimate the muscular utilization ratio (MUR) of paretic plantarflexors, hip flexors and extensors during their concentric action at self-selected and maximal gait speeds. First, it was hypothesized that peak MUR would increase significantly with gait speed. As shown in healthy individuals [41], the increase would be more pronounced at the hip than at the ankle. Second, it was thought that peak MUR would be greater at the ankle than at the hip joint. Third, it was supposed that residual strength would be negatively related to peak MUR values such that weaker participants would tend to have greater levels of effort than stronger ones.

## 2. Methodology

### 2.1. Participants

Participants were recruited at two rehabilitation centers in the Montréal area (Institut de réadaptation de Montréal and Hôpital de réadaptation Lindsay). The inclusion criteria were as follows: (a) have sustained a unilateral stroke at least 6 months before entering the study, (b) be able to walk 10 m independently with or without a cane, (c) present with residual weakness in the paretic lower limb, and (d) have an activity tolerance of at least 2 h including rest periods. Participants were excluded if they presented with comprehensive aphasia, incontinence, an unstable medical condition (e.g., heart problem), a history of injury and severe sensory deficits (anesthesia) in the lower limbs. This information was obtained from participants, proxy and clinical charts, and the primary-care physician was consulted if required. Informed consent was obtained from each participant before the evaluation session, and the rehabilitation center's ethics board approved the study.

### 2.2. Clinical evaluation

A clinical examination, performed by a physical therapist, provided a detailed description of demographic data for all participants. In addition, physical impairment, spasticity, the perception threshold of touch-pressure in the lower limb, balance and gait speed (self and maximal speeds) were evaluated.

Lower-limb physical impairments were assessed with the lower extremity component (leg and foot) of the Chedoke–McMaster Stroke Assessment [16]. The presence and severity of physical impairments was quantified on a 7-point