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# Influence of M. tibialis anterior fatigue on the walk-to-run and run-to-walk transition in non-steady state locomotion

Segers V[a], Lenoir M[a], Aerts P[a,b], De Clercq D[a,*]

[a] *Department of Movement and Sport Sciences, Faculty of Medicine and Health Sciences, Ghent University, Watersportlaan 2, B-9000 Gent, Belgium*
[b] *Department of Biology Laboratory for Functional Morphology, University of Antwerp, Belgium*

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**Abstract**

The purpose of this study was to examine the influence of muscular fatigue of tibialis anterior (TA) on the walk-to-run transition (WRT) and run-to-walk transition (RWT) when speed is altered at different constant accelerations ($a = 0.01$, 0.07 and 0.05 m s$^{-2}$). Twenty women (height: $168.9 \pm 3.36$ cm) performed WRTs and RWTs on a motor-driven treadmill, before and after a protocol inducing muscular fatigue of the TA.

WRT-speed decreased after TA fatigue whereas RWT-speed did not change except during the intermediate deceleration. Integrated EMG (iEMG) of the activity burst of TA around heel contact was examined in the last steps before transition, the transition step and the first steps after transition. iEMG increased before WRT, then decreased after transition to running. In the RWT the opposite was observed: iEMG increased after RWT, then decreased with decreasing walking speed. After inducing fatigue in the TA, there was a decrease in iEMG in the WRT whereas no influence of fatigue was found on iEMG in the RWT.

As a result of TA fatigue, WRT occurred at a lower speed, probably to avoid over-exertion of the TA. This indicates that the TA is a likely determinant of WRT as previously reported. The RWT, on the other hand, was not altered following TA fatigue, which would indicate that WRT and RWT are determined by different factors.


*Keywords:* Gait transition; M. tibialis anterior; EMG; Biomechanics

## 1. Introduction

Increasing speed results in a change from walking to running. Decreasing speed on the other hand results in the opposite transition from running to walking [1–4]. Both transitions occur at a preferred speed [5]. Nevertheless, it is not yet entirely clear why humans prefer that specific speed to change from one mode to another [6].

One of the most obvious reasons for the transition is metabolic cost, that is, a change to another type of locomotion reduces oxygen consumption. Regarding the relationship between metabolic cost and transition, conflicting results have been found. Some studies suggested that the walk-to-run transition (WRT) is closely linked to the minimization of metabolic cost [7,8]. Others found evidence to reject this energy optimisation hypothesis [9–13]. This contradiction can be partly explained by the difficulties in directly measuring the metabolic cost [6,7].

In the absence of a clear metabolic trigger, it is unclear why subjects perceive walking as ''harder'' than running at transition speed [10,14]. Subjects might use information from peripheral receptors, from the activity in the neural networks controlling locomotion, as well as from previous experience, to trigger transition and achieve a more comfortable mode of locomotion [15]. This is supported by evidence showing that perceived effort during low-intensity exercise (estimated by the rate of perceived exertion) originates from motor outflow commands to muscles (quantified by muscle activation) and, to a lesser degree, from the afferent information of the actual force developed by the muscles [16].

* Corresponding author. Tel.: +32 9 264 63 22; fax: +32 9 264 64 84.
*E-mail address:* Dirk.DeClercq@UGent.be (D. De Clercq).

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The larger, proximal muscle groups are not activated near their maximal level when walking or running at a speed close to WRT-speed. Therefore, muscular activation level and muscular stress level is low [2,3]. The smaller and distal tibialis anterior muscle (TA), however, is activated near its maximum capacity and experiences high muscular stress around WRT-speed [2]. The amplitude of peak EMG of the TA increased with increasing walking speed but suddenly decreased after transition [2]. Also, at WRT-speed, critical levels of ankle angular velocities and accelerations are reached [3,5]. This apparently crucial role of the TA led to the hypothesis that the WRT is determined at the ankle region [2,5]. EMG of the TA during walking and running has a typical phasic activity pattern with a burst during the eccentric foot plantarflexion movement following heel contact. This eccentric activity may be causing an increased perceived exertion, which would serve as protective mechanism to prevent further damage [17].

Although WRT may be triggered by information arising around the ankle region, this may not necessarily be the case for run-to-walk transition (RWT). The ankle velocity and acceleration change from a lower value in running to a higher value in walking [5]. Therefore, Prilutsky and Gregor [3] suggested that RWT might be controlled by other muscle groups, namely the muscles active during stance (soleus, gastrocnemius and vastus lateralis). The perception of increased effort in these support-related muscles is likely to be required for the acceleration and deceleration of the body's centre of mass and the larger peaks of vertical ground reaction forces [3,18].

The purpose of this study was to examine transition speed and activity of the TA in a protocol with gradually changing speed to investigate the actual transition step(s) when accelerating across transition speed. By inducing fatigue in the TA, local perceived exertion is expected to increase [19] which then decreases WRT-speed[2].

The main hypotheses of this study are: (1) WRT occurs at a lower speed following TA fatigue, while RWT remains unaffected, (2) integrated EMG (iEMG) will increase as walking speed increases in the WRT, then decrease after WRT, both before and after TA fatigue and (3) TA activity in the RWT will not be affected by transition nor by TA fatigue.

## 2. Materials and methods

### 2.1. Subjects

Twenty physically active female subjects took part in the present research, having signed informed consent (Table 1). Subjects of height between 1.65 and 1.75 m were chosen to minimize possible influence of anthropometric values on transition speed [20]. At the time of the study all subjects were free from any disease or injury that could affect the results. The ethical committee of Ghent University Hospital approved the experimental protocol.

Table 1
Subjects characteristics: mean ($X$) and standard deviation (S.D.) for height, body mass, leg length and age

| | $X$ | S.D. |
|---|---|---|
| Height (cm) | 168.9 | 3.4 |
| Weight (kg) | 63.2 | 5.9 |
| Leg length (cm) | 91.4 | 1.8 |
| Age (years) | 24.5 | 2.8 |
| Physical activity[a] (h/week) | 2.82 | 0.95 |

[a] Sports on competitive level.

### 2.2. Treadmill protocol

The experiment was divided into two sessions. For each session, every subject performed 30 trials divided into six blocks of five trials with a resting period of 30 s between each block. Each block was characterized by a constant acceleration. This type of protocol with gradually changing speed was chosen because transition is thought to be a process [4,21] with acceleration as an important task constraint [22]. The accelerations were 0.10, 0.07, 0.05, −0.10, −0.07 and −0.05 m s$^{-2}$. Positive and negative accelerations, respectively, caused WRT and RWT. By choosing these values, the acceleration at which WRT-speed probably equals RWT-speed (no hysteresis at 0.07 m s$^{-2}$) [22] was included together with distinctly lower (0.05 m s$^{-2}$) and higher (0.10 m s$^{-2}$) values. The blocks were randomly selected for subjects, while alternating positive and negative accelerations. The first block was not incorporated in the calculations but was considered a familiarization trial.

During the first session, all subjects were familiarized with the treadmill by performing treadmill locomotion at different speeds [23] for at least 15 min. The second session began with the fatigue-inducing protocol followed by the treadmill protocol. The time elapsed between the fatigue-inducing and treadmill protocol was maximally 2 min to exclude potential recovery of TA.

The actual speed of the treadmill was on-line electronically registered (5 Hz) and synchronized with video recordings by means of LED's.

### 2.3. Fatigue protocol

Subjects were seated with thighs and trunk strapped to the chair in order to eliminate the undesired use of these segments in the fatigue protocol. A sub-maximal load (±70% of one repeated maximum) was placed on the "Tib Exerciser", a fitness device used to train the TA. Subjects were asked to move the load up and down at a constant speed. This was supervised by an experienced researcher to create a standardized protocol. Subjects performed series of 15 repetitions with a 30-s break between successive series, until exhaustion was reached. If a series was not completed, subjects were offered a second try after a 1 min break. An adapted Borg scale (scale 1–10) was used to scale localized muscle fatigue [24].