PROLONGED WALKING INDUCES NEUROMECHANICAL CHANGES IN THE HUMAN LOWER LIMB

Neil J. Cronin, Jussi Peltonen, Thomas Sinkjaer and Janne Avela

Griffith University, Australia, University of Jyväskylä, Finland, Aalborg University, Denmark;
email: n.cronin@griffith.edu.au

SUMMARY

This study investigated whether neural compensation was evident within the triceps surae complex in response to a prolonged walking protocol lasting for 60 minutes at 4.5 km/h. Muscle activity, ankle and knee joint kinematics and maximal muscle compound action potentials (M-max) were recorded at 5 minute intervals throughout the protocol. Ultrasound was also used to estimate fascicle lengths at the beginning and end of the experiment. The results of this study demonstrate the existence of neural compensation between triceps surae muscles after prolonged walking, whereby MG activity decreased and soleus activation increased by a corresponding amount. These findings support the hypothesis that tendinous tissue compliance is altered after prolonged walking, and highlight the muscle-specificity of these changes, as well as their effects on neural activation and motor control.

INTRODUCTION

When humans walk, different muscles are activated sequentially in order to generate an apparently smooth, fluent motion. During unconstrained walking, the particular muscles that are activated and the degree of activation of these muscles are assumed to remain approximately constant across consecutive step cycles when walking for a short time [1]. It is unknown whether this activation strategy is maintained when walking for a longer time, i.e. at least several minutes.

It has previously been reported that walking for approximately 75 minutes leads to an increase in the compliance of the tendinous tissues in the soleus muscle-tendon unit (MTU), resulting in a shift of stretch distribution from the muscle fascicles towards the tendinous tissues during the stance phase. Soleus muscle activation also generally decreased by the end of the walking protocol [2]. These data suggested a possible link between mechanical changes in muscle fascicle behaviour and neural changes in the soleus muscle.

However, this study was unable to assess the behaviour of other triceps surae muscles, which are assumed to act as synergists to the soleus muscle. Previous studies using fatiguing protocols have reported that a decrease in the activation of an individual muscle may be compensated by an increase in activation of synergistic muscles, for example in the quadriceps [3]. In the present study, we sought to investigate whether neural compensation was evident within the triceps surae complex in response to a relatively low intensity, prolonged period of walking.

METHODS

Thirteen healthy subjects (5 males, 8 females; Age 27±3 years; Height 171±8 cm; Body mass 67±10 kg) walked on a custom-made motorised treadmill for 60 minutes at 4.5 km/h. During this time, muscle activity, ankle and knee joint kinematics and maximal muscle compound action potentials (M-max) were recorded at 5 minute intervals, resulting in the collection of 13 data sets per subject. Within each measurement interval, electromyographic activity (EMG) was recorded from approximately 50 steps. M-max data were then collected from 3 steps, with each stimulation timed to occur at precisely the mid-stance phase. Within each interval, muscle activity data from medial gastrocnemius (MG) and soleus were later normalised to M-max measured from the same 5 minute interval. During the first and last measurement intervals (0 and 60 minutes, respectively), ultrasound data were collected from 5-8 steps to enable MG and soleus fascicle lengths to be estimated. A schematic of the experimental setup is shown in Figure 1.

RESULTS AND DISCUSSION

After 1h of walking, the mean range of ankle rotation during the stance phase increased by 3.3±0.3° (P<0.05) from

Figure 1: Schematic of the experimental setup. EMG: electromyography; FSR: force-sensitive resistor.
27.8±7.1° to 31.1±7.0°. The range of knee rotation did not change significantly (P=0.705). Mean background EMG decreased across the group by 10.0±0.1% (P<0.05) and 13.1±0.2% (P<0.01) in soleus and MG, respectively. However, after normalising the data to M-max measured during walking, soleus EMG actually increased by 9.3±0.2% (P<0.05) and MG EMG decreased by 9.3±0.3% (P<0.01). In MG, fascicle length at the point of ground contact shortened between the first and last measurement intervals by 4.45 ± 0.99% (P<0.001). In soleus, fascicle length at ground contact was unchanged (P=0.988). Between the first and last measurement intervals, MG fascicle lengthening amplitude, measured as the difference between the shortest length immediately after ground contact and peak length during the stance phase, decreased by 44 ± 13% (P<0.001), whereas soleus fascicle lengthening amplitude was unchanged (P=0.650). Data from one subject are shown in Figure 2.

The results of this study demonstrate that muscle activity is modulated in a muscle-specific manner in individual triceps surae muscles after prolonged walking, despite the absence of major changes in knee and ankle joint kinematics. After normalising the EMG data to M-max measured during walking, MG activity decreased, and this was compensated by a corresponding increase in soleus activation. These neural changes were also generally mirrored by mechanical changes, as MG fascicles were shorter and lengthened less during the stance phase at the end of the protocol, although no clear changes occurred in soleus fascicle behaviour. These findings support our previous data whereby tendinous tissue compliance was altered after prolonged walking [2], and suggest that these changes may be muscle-specific. As MG and soleus share a distal tendon but exhibited different neural and mechanical behaviour, the site of change in compliance may primarily be the aponeurotic tissues, although this issue requires further examination. These findings collectively highlight the influence of muscle-tendon mechanics on neural activation, as well as the muscle specificity of these effects.

**CONCLUSIONS**

In this study, a low-intensity walking protocol led to neural and mechanical changes that differed between the MG and soleus muscles, in spite of their shared distal tendon. In MG, the walking intervention led to a shortening of the muscle fascicles, a shift of stretch distribution from the muscle fascicles towards the tendinous tissues during the stance phase and a decrease in muscle activation of approximately 10%. In soleus, no clear changes in muscle-tendon stretch distribution patterns were detected, but muscle activation increased by approximately 10%, suggesting a compensatory neural strategy between these muscles. We attribute these changes primarily to muscle-specific alterations in the compliance of aponeurotic tissues, although a moderate influence of MG fatigue cannot be completely excluded. These findings, in combination with previous data, highlight the ability of the central nervous system to maintain a relatively constant global movement pattern in spite of local neural and mechanical changes in individual muscles.

**REFERENCES**