BIOMECHANICAL REORGANISATION OF STEPPING INITIATION DURING ACUTE DORSIFLEXOR FATIGUE

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SUMMARY
During voluntary step initiation (SI), propulsive forces are generated during anticipatory postural adjustments (APA) which accelerate the centre of gravity (CG) in the desired direction. These propulsive forces are implemented by ankle synergy, bilateral soleus inhibition followed by activation of tibialis anterior (TA). This study investigated whether and how the central nervous system (CNS) adapts APA programming for SI to bilateral dorsiflexor fatigue. Eight young healthy participants initiated stepping before and after a protocol designed to generate fatigue in ankle dorsiflexors. Results showed that, with fatigue, the level of TA activation during APA, anticipatory postural dynamics (backward centre-of-pressure displacement and forward CG velocity) and related motor performance (peak of CG velocity) were attenuated, while APA duration and total SI duration increased. These changes were interpreted as reflecting a protective strategy aiming to preserve the integrity of the fatigued muscles, rather than an impairment associated with muscle weakness. Along with the literature on the effect of fatigue on APA associated with upper limb tasks, these results suggest that the CNS may prioritise either the protection of fatigued muscle(s) or the maintenance of motor performance, depending on the level of solicitation of the postural joints recruited during APA.

INTRODUCTION
Step initiation (SI) has been defined as the transient period between upright stance to the time of swing foot contact with the ground [2]. It is composed of a postural phase (the so-called “anticipatory postural adjustments”, APAs) followed by an execution phase. During APAs, the initial propulsive forces required to reach the intended velocity of the centre of gravity (CG) are generated [2]. These APA systematically include backward centre of pressure (CP) displacement concomitant with forward CG acceleration. This dynamical pattern is implemented by ankle muscle synergy, bilateral soleus inhibition followed by strong tibialis anterior (TA) activation. The present study investigates the adaptability of this anticipatory postural control of SI to internal perturbation induced by ankle muscle fatigue. Previous studies from the literature have investigated the effect of postural muscle fatigue on APA associated with various upper limb tasks from quiet standing posture [e.g. 1,4,8,9,10]. These studies reported that, under fatigue state, APA onset occurred earlier in the muscles, resulting in longer APA duration. Because both the amplitude of anticipatory CP displacement and focal movement performance (e.g. maximal pointing velocity) remained unchanged with fatigue, this longer APA duration was thought to reflect an adaptive change aimed to compensate for the reduced capability of force production in the postural muscle system (“compensatory strategy”). It is noteworthy that, during APA, the backward CP displacement, the level of ankle dorsiflexor activation and the ankle joint movement are much greater during SI than during forward upper limb tasks (e.g. [11]). The ankle joint complex is therefore solicited much more and thus, is more subject to damage in a fatigued state. So, this study tested the hypothesis that, during SI performed under a fatigued state of ankle dorsiflexors, the preferential purpose of the central nervous system (CNS) might be not to obtain invariant anticipatory postural dynamic and motor performance (as during upper limb tasks), but might rather be to protect the fatigued ankle joint complex from alteration (“protective strategy”).

METHODS
Participants (n=8) performed ten trials under each of the two following conditions: under the “no fatigue” condition (NF), participants initiated a forward step at spontaneous speed in a normal muscular state; under the “fatigue” condition (F), participants initiated a forward step after a fatiguing procedure designed to obtain major fatigue in the ankle dorsiflexors. In three participants, SI was also performed at maximal velocity to ensure that the level of TA activation and the CG velocity could be increased. The fatiguing procedure consisted of series of 30 seconds isometric contractions (IC) of both TA at 60% maximum IC, followed by 15 seconds rest. These series were performed until exhaustion (see [7] for details on the fatiguing protocol). Maximal IC was quantified before and after the fatiguing procedure. During the fatiguing procedure and the SI trials, the electrical activity of both TA was recorded with surface bipolar electrodes (Biometrics, Ltd). SI trials were performed on a large force plate (Bertec, Columbus).

RESULTS AND DISCUSSION
Participants performed 27±4 fatiguing series before the level of fatigue was reached. The maximal isometric force significantly decreased by 33% after the fatiguing series (t=3.07, P<0.05) which attested that fatigue occurred. In F and NF, swing foot-off was systematically preceded by dynamic and EMG phenomena corresponding to APA (Figure 1). These APA included backward CP displacement concomitant with
forward CG acceleration. The CG velocity increased progressively until it reached a maximum value a few milliseconds after the time of swing foot-contact. For both legs, the TA was strongly activated during the APA time window. Statistical analysis revealed that APA duration \((t=3.07, P<0.01)\) and total SI duration \((t=2.65, P<0.05)\) reached significantly higher values in F than in NF. In contrast, anticipatory backward CP displacement \((t=5.3, P<0.01)\), anticipatory CG velocity \((t=3.06, P<0.01)\) and peak of CG velocity \((t=5.21, P<0.01)\) reached significantly lower values in F than in NF. Statistical analysis further showed that the level of TA activation was significantly lower in F than in NF for both the stance \((t=2.47, P<0.01)\) and swing leg \((t=6.14, P<0.01)\).

These results show that, under a fatigued state of ankle dorsiflexors, the level of TA activity, the anticipatory postural dynamics and related motor performance (peak CG velocity) were attenuated, while APA duration and SI duration increased. These changes are in line with the hypothesis that the CNS used a “protective strategy” aimed to preserve the integrity of the fatigued muscles, rather than a “compensatory strategy” aimed to obtain invariant motor outcome. Interestingly, similar changes were obtained by [6] during SI made under experimental pain induced by injection of hypertonic saline into TA. These results has been emphasized to be in accordance with the so-called “pain-adaptation model” [5] which predicts decreased EMG activity of the agonist muscle, increased EMG activity of the antagonist muscle, and slower and less powerful movements during muscle pain in order to protect the painful muscle. This fit with the present results might stem partly from the activation of common neurophysiological pathways during the fatiguing procedure involved in this study and in the sensation of pain (e.g. [3]). Along with the literature on the effect of fatigue on APA associated with upper limb task [1,4,8,9,10], the present results suggest that the CNS may either prioritise the protection of fatigued muscle(s) or the maintenance of unchanged motor outcome, depending on the level of solicitation of the postural joints recruited during APA.

**CONCLUSION**
The present results, along with the literature [1,4,8,9,10], highlight the task-dependant effect of fatigue on anticipatory postural control associated with voluntary movement.

**REFERENCES**