ACUTE AND DELAYED FATIGUE EFFECTS OF EXHAUSTIVE STRETCH-SHORTENING EXERCISE ON THE INITIAL ADJUSTMENTS OF BAREFOOT RUNNING PATTERN

[1, 2] Cédric Morio, [2] Caroline Nicol, [2] Joëlle Barthèlemy, [2] Eric Berton and [1] Charlie Barla
[1] Oxylane Research, Villeneuve d'Ascq, France, web: www.oxylane-research.com
[2] UMR 6233, Institut des Sciences du Mouvement, Université de la Méditerranée, Aix-Marseille II, France

INTRODUCTION

Stretch-shortening cycle (SSC) defines natural forms of ground locomotion. For effective SSC action, three conditions are fundamental: a well-timed preactivation prior to impact, a short and fast stretching action, and an immediate transition between the stretch and shortening phases [1]. Considering the challenge of performing effective SSC task, it is of interest to examine the neuro-mechanical adjustments that might take place with fatigue. Exhaustive SSC exercises are known to induce both acute and delayed functional impairments, with associated delayed onset muscle soreness (DOMS) and sensorimotor adjustments [2]. Intermittent form of SSC exercise are reported to induce greater delayed than acute functional effects. In both fresh and fatigue testing conditions, most studies concentrated on the stabilized SSC pattern and, thus, bypassed the initial neuro-mechanical adjustments that may be expected to occur prior to stabilization. In running fatigue studies, different kinematics changes have been reported in both acute [3] and delayed [4] post-exercise recovery phases, but data are still lacking on the associated neuromuscular adjustments.

The present study examined the neuro-mechanical adjustments that might take place in running depending on the subject's state: fresh vs. fatigued. Special emphasis was put on the initial adjustments of the running pattern at given submaximal velocity. After intermittent exhaustive SSC exercise, our first hypothesis was that the delayed recovery phase would be characterized by larger neuro-mechanical adjustments than those observed either in the fresh state or in the acute recovery phase. This was thus expected to result in closer stabilized running patterns. Our second hypothesis was that the delayed recovery phase would be characterized by muscle protective strategies rather than osteoarticular ones at submaximal running velocity.

METHODS

Ten healthy male subjects (26 ± 2 years; 75 ± 10 kg; 1.79 ± 0.06 m) volunteered to participate in this study. An exhaustive intermittent rebound exercise was performed with the lower limbs on a sledge apparatus. This exercise consisted of series of 25 bilateral rebounds against the sledge force plate, with inter-series rests of 3 min. The rebound height was set at 80 % of the individual maximal rebound performance. Functional fatigue effects were quantified before (PRE), 3 minutes after (POST) and 2 days later (D2) in a maximal drop-jump test and during a 5 minute barefoot treadmill run performed at submaximal velocity ($Fr = v^2/g*L_{lowerlimb} = 1$). DOMS was recorded twice daily and for a week using a CR10 Borg scale.

The treadmill run analysis included 3D kinematics of the right lower limb at 150 Hz during the last 15 seconds of the first (BEG) and fifth (END) minutes of running. This allowed examination of the expected initial pattern adjustments. Surface EMG activity from 7 selected muscles and 3D tibial accelerations (TAcc) of the right lower limb were recorded simultaneously at 2400 Hz. The recorded running steps were divided into preactivation, braking (from touchdown to the lowest hip position) and push-off (until toe-off) phases. The corresponding averaged EMG (aEMG) values were calculated for the soleus (SOL), gastrocnemii (GAM, GAL), tibialis anterior (TA), peroneus longus (PL) and vastii (VM, VL) muscles. Peak to peak amplitudes and wavelet frequency content of tibial accelerations were calculated for the 0-100 ms of the braking phase. Vertical lower limb stiffness (k_{vert}) was extrapolated from contact and flight phase durations [5].

Initial adjustments (BEG-END) and testing time (PRE-POST-D2) effects on the treadmill running pattern were evaluated using a two-way analysis of variance with repeated measures (initial adjustments x testing time). In case of a significant main effect of testing time, Tukey *post-hoc* tests were performed to compare its effects among BEG and END values, respectively. The α-level of significant was set as 0.05.

RESULTS AND DISCUSSION

The drop jump test showed similar reductions in maximal rebound height at POST (-5.9 ± 4.1 %) and D2 (-6.2 ± 7.6 %) ($p = 0.01$). DOMS peaked at 36 hours and remained elevated (4 ± 2) at D2 in quadriceps and triceps surae muscle groups. The submaximal treadmill run analysis revealed significant "initial adjustments" and "testing time" effects. Opposite to our first hypothesis, no interaction was found between the two main effects. On the other hand, our second hypothesis of muscle protective strategies was well supported by the present data.

Table 1 presents the significant initial (BEG-END) neuro-mechanical adjustments observed in each running test that included step frequency reductions as well as large EMG decreases in both preactivation and push-off phases. These

EMG changes are in agreement with our earlier PRE- and POST-fatigue observations in another SSC task [6], and considered as reflecting an optimization of the SSC (running) pattern. On the other hand, midfoot abduction and knee flexion excursions were found to increase from BEG to END. These changes were not sufficient to affect significantly the tibial accelerations parameters.

Table 1: Relative group mean (± sd) neuro-mechanical changes between the first and the fifth minutes of each running bout at the three testing times before (PRE), after (POST) and at two days (D2). * $p < 0.05$.

(delta %)	**PRE** (BEG-END)	**POST** (BEG-END)	**D2** (BEG-END)
Step frequency*	-2.4 ± 3.3	-2.5 ± 1.3	-1.3 ± 2.0
Vertical stiffness*	-4.4 ± 5.3	-4.1 ± 3.9	-3.7 ± 4.5
Preactivation :			
GAM aEMG*	-11 ± 30	-12 ± 48	-18 ± 30
Braking phase:			
Knee flexion*	7 ± 10	5 ± 6	7 ± 9
Midfoot abduction*	10 ± 9	10 ± 14	14 ± 14
Push-off phase :			
SOL aEMG*	-15 ± 20	-7 ± 20	-25 ± 18
GAM aEMG*	-10 ± 24	-11 ± 18	-24 ± 13
GAL aEMG*	-15 ± 20	-16 ± 19	-23 ± 16
PL aEMG*	-9 ± 16	-13 ± 13	-26 ± 13
TA aEMG*	-22 ± 32	-3 ± 45	-15 ± 31

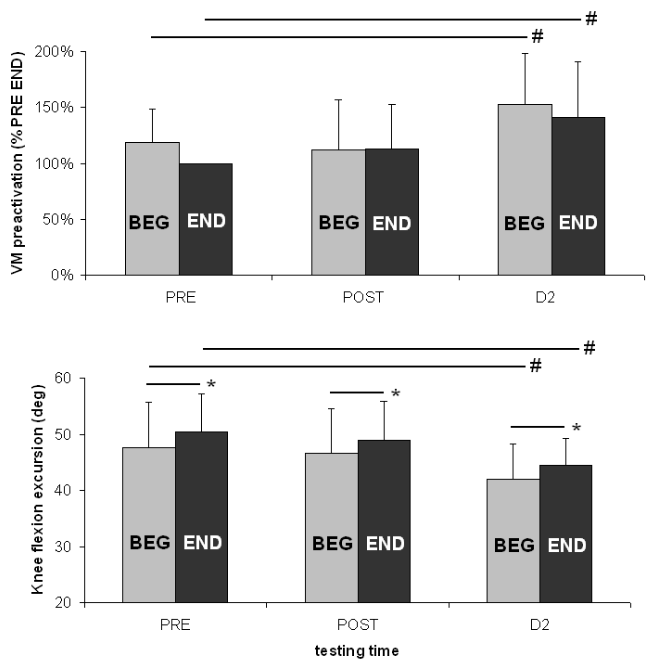

Figure 1: Group mean (+sd) values of vastus medialis (VM) preactivation (*upper graph*) and knee flexion excursion (*lower graph*) at the first (BEG) and fifth (END) minutes of the run at the three testing times. * means significant BEG-END increases. # indicates significant PRE-D2 changes ($p < 0.05$).

As expected after an intermittent form of exhaustive SSC exercise, the treadmill run presented no acute (PRE-POST) fatigue effect, but significant delayed (PRE-D2) modifications of the running pattern. On the other hand, the absence of interaction effect shows that the amplitude of the initial neuro-mechanical adjustments was not significantly affected by the subject's fatigue state. However, the D2 treadmill run started and ended at significantly higher VM preactivation and lesser knee flexion excursion than in the PRE condition (Figure 1). VL preactivation was also significantly higher at the initiation of the D2 run.

The absence of larger adjustments at D2 might be considered as reflecting subject's inability to maintain a similar running pattern. However, the submaximal barefoot running task was still performed with no associated signs of SSC deterioration such as increased activation during the stance phase or modified step frequency, vertical stiffness and post-impact tibial acceleration. These observations would rather suggest a maintained SSC efficacy with appropriate adjustments of the running pattern to the fatigue state.

Comforting the existence of a major knee strategy at D2 [4] no significant change was observed, neither in leg muscles activation during the preactivation and braking phases nor in ankle and midfoot joint angles. In circumstances where DOMS is involved, reduced knee flexion could have aimed at preventing additional vastii muscle pain [4]. The absence of systematic changes in GA preactivation might be attributed to the fact that biarticular GA fascicles are mostly shortening [7] in running.

CONCLUSIONS

The present examination of the initial neuro-mechanical adjustments of the running pattern did contribute to the understanding of the SSC functional fatigue effects. The delayed recovery phase revealed a centrally regulated muscle protective strategy that resulted in a different running pattern, which is expected to have optimally compensated for the contractile failure.

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