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Research article

Effects of between-set interventions on neuromuscular function during isokinetic maximal concentric contractions of the knee extensors

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Abstract
The presents study investigated the effects of between-set interventions on neuromuscular function of the knee extensors during six sets of 10 isokinetic (120°·s^{-1}) maximal concentric contractions separated by three minutes. Twelve healthy men (age: 23.9 ± 2.4 yrs) were tested for four different between-set recovery conditions applied during two minutes: passive recovery, active recovery (cycling), electromyostimulation and stretching, in a randomized, crossover design. Before, during and at the end of the isokinetic session, torque and thigh muscles electromyographic activity were measured during maximal voluntary contractions and electrically-evoked doublets. Activation level was calculated using the twitch interpolation technique. While quadriceps electromyographic activity and activation level were significantly decreased at the end of the isokinetic session (-5.5 ± 14.2 % and -2.7 ± 4.8 %; $p < 0.05$), significant decreases in maximal voluntary contractions and doublets were observed after the third set (respectively -0.8 ± 12.1% and -5.9 ± 9.9%; $p < 0.05$). Whatever the recovery modality applied, torque was back to initial values after each recovery period. The present results showed that fatigue appeared progressively during the isokinetic session with peripheral alterations occurring first followed by central ones. Recovery interventions between sets did not modify fatigue time course as compared with passive recovery. It appears that the interval between sets (3 min) was long enough to provide recovery regardless of the interventions.

Key words: Electromyography, electromyostimulation, stretching, recovery, maximal strength.

Introduction

Isokinetic exercises consisting of several sets of maximal concentric and/or eccentric contractions have been used to study neuromuscular fatigue (Babault et al., 2006; Linnamo et al., 2000; Michaut et al., 2003). Most of these studies assessed fatigue at the end of the exercise (Gauche et al., 2009; Hill et al., 2001) but little is known regarding fatigue time course within the exercise and whether applying different types of recovery interventions between sets would modify this fatigue time course. This knowledge would be useful in order to better understand how fatigue develops during this type of session and how to limit its appearance.

Indeed, this type of exercise has been demonstrated to induce metabolites accumulation (Linnamo et al., 2000) that might progressively decrease the exercise intensity (Steele et al., 2003). Therefore, it could be of interest to optimize recovery between sets in order to limit fatigue appearance. Previous studies investigated the effect of cycling, stretching or electromyostimulation on recovery from exercise (Miladi et al., 2010; Spierer et al., 2004), and these might enhance between-set recovery. In fact, these interventions have shown to increase blood flow (Gupta et al., 1996) and metabolites removal (Neric et al., 2009; Toubekis et al., 2008). However, no previous studies have applied these interventions between sets. It was hypothesized that cycling, stretching or electromyostimulation inserted between sets during an isokinetic exercise would delay fatigue compared with passive recovery.

Therefore, the first aim of this study was to evaluate fatigue time course during an isokinetic exercise composed of six sets of ten maximal concentric contractions separated by three minutes of passive recovery. The second aim of this work was to assess if currently used recovery interventions (bicycle, stretching, electromyostimulation) would be more effective than passive recovery to limit fatigue appearance during the session (Barnett et al., 2006). These three interventions were chosen because they are cheap, easy to apply and have already demonstrated their effectiveness after exercise (Miladi et al., 2010; Spierer et al., 2004).

Methods

Subjects

Twelve healthy men, with no previous history of injury to the lower extremity participated in this study (age: 23.9 ± 2.4 yrs, weight: 74.6 ± 7.8 kg, height: 1.77 ± 0.05 m). All were physically active and used to upper- and lower-body strengthening exercises in their own sport. However, none of them had ever been engaged in any training or testing protocol on an isokinetic dynamometer. Each read and signed a written informed consent document outlining the procedures of the experiment. The study was conducted according to the declaration of Helsinki and approval for the project was obtained from the local Institutional Review Board. Subjects were all instructed to refrain from training during the entire protocol. According to power calculation (Statistica 8.0, Statsoft Inc, Tulsa, USA), this sample size was high enough to test fatigue time course and differences between recovery interventions.

Experimental design

The experiment was based on four sessions each corresponding to a recovery mode randomly assigned. Sessions were separated by at least seven days and conducted at the same time of the day.

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One week before the protocol onset, subjects performed several concentric contractions (120°·s^{-1}) on an isokinetic dynamometer for familiarization. Single twitches were also delivered during this session in order to accustom the subjects to femoral nerve electrical stimulation. During all sessions, subjects were seated in comfortable upright position on the isokinetic dynamometer (BIODEX system 2, Biodex corporation, Shirley, NY) with a 95° hip angle. Velcro straps were applied tightly across the thorax. The leg was fixed to the dynamometer lever-arm and the axis of rotation of the dynamometer was aligned to the lateral femoral condyle, indicating the anatomical joint axis of the knee.

Each session began with a standardized warm-up consisting of 10 to 15 progressive dynamic leg extensions performed at 120°·s^{-1}. Then, optimal stimulation intensity was determined and subjects underwent tests (described below) that were repeated during and after the isokinetic session in order to determine the fatigue time course (Figure 1).

The isokinetic session included six sets of 10 maximal concentric contractions of the right quadriceps (100° range of motion from 0 to 100° – 0° corresponding to knee fully extended) at 120°·s^{-1}, separated by three minutes. Subjects were strongly encouraged to contract maximally. For each session, one of the four recovery modes was applied between sets bilaterally for two minutes. The order of the recovery modes application was purely randomized by drawing lots for each subject, at the beginning of each session.

Passive recovery (PR). Subjects remained static on the seat of the ergometer in a relaxed position (75° knee flexion).

Active recovery (AR). Light pedalling on a bicycle (50 Watts) at 55 rpm (Bike Forma, Technogym Gambettola FC – Italy).

Stretching (ST). On one foot, with one hand on a wall for balance, subject hold the other foot with the opposite hand and raised the heel to the buttocks. The quadriceps femoris was maximally stretched and the position was maintained during 20 s. Both legs were alternately stretched three times.

Electromyostimulation (EMS). Low-frequency stimulation of knee extensor muscles was performed using a commercially available program for active recovery (9 Hz, pulse width 400 µs, rise time: 1.5s, fall time: 1.5s; Compex Energy, Compex SA, Ecublens Switzerland). Stimulation intensity was self-chosen, strong but comfortable (i.e, 20-30 mA). Quite similar stimulation characteristics have previously been tested for recovery after fatiguing exercises (Lattier et al., 2004). Pairs of positive electrodes (5 cm × 5 cm) were placed as close as possible to motor points of vastus lateralis and vastus medialis muscles. Rectangular negative electrodes (10 cm × 5 cm) were placed transversally on the proximal portion of both thighs. Electrodes were only removed at the end of the session.

Measurements

Before (pre Set 1), during (post Set 1, pre and post Set 3 and pre Set 6), and after (post Set 6) the isokinetic session, tests were performed to investigate neuromuscular fatigue time course (Figure 1). Tests, involving MVC and evoked contractions, were carried out on the isokinetic dynamometer, in isometric conditions (75° knee flexion). Changes in torque generated during the first three and last repetitions of sets 1, 3 and 6 were recorded.

MVC. Two 5-s MVC (separated by 15 s) were performed at pre Set 1 and post Set 6, and the highest value of the two was retained for further analysis. To avoid additional fatigue, only one isometric MVC was performed at post Set 1, pre Set 3, post Set 3 and pre Set 6.

Evoked contractions. Quadriceps contractile properties were studied using femoral nerve stimulations. Electrical impulses were delivered through a pair of surface electrodes. The anode (self-adhesive stimulation electrode, 10 cm × 5 cm) of the electrical stimulator (Digitimer DS7, Hertfordshire, England) was pasted halfway between the superior aspect of the greater trochanter and the inferior border of the iliac crest. The cathode (10 mm diameter ball probe) was pressed in the femoral triangle and moved to the position allowing the biggest contraction. At the beginning of each session (after warm-up), optimal stimulation intensity was determined isometrically using single twitches (1-ms duration, 400 V maximum voltage and intensity ranging from 60 to 200 mA stimulations) separated by 5 s, with progressively increasing intensity until twitch torque failed to increase. This maximal intensity was used during the remainder of the session: two electrical impulses (doublet) separated by 10 ms (100 Hz) were applied. Stimulations were delivered at rest before each MVC to assess contractile properties,

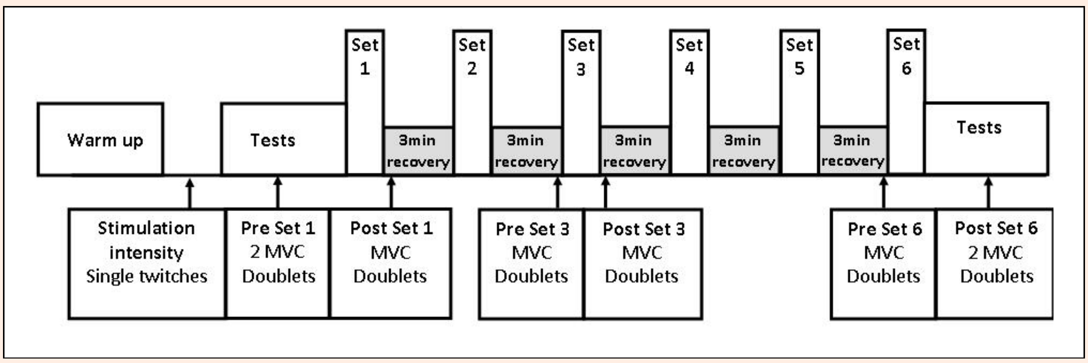

Figure 1. Schematic view of the experimental design.

Table 1. Mean values (SD) of neuromuscular parameters before (Pre S1) and after (Post S6) an isokinetic exercise with four different recovery modalities.

		PR	AR	ST	EMS	Average
Pd (Nm)	**Pre S1**	70.7 (18.7)	69.2 (16.5)	70.5 (20.0)	72.5 (17.8)	70.7 (18.3)
	Post S6 *	65.6 (21. 1)	66.6 (17.9)	63.10 (15.7)	66.1 (20.6)	65.4 (19.0)
MVC (Nm)	**Pre S1**	183.7 (64.2)	191.3 (76.7)	196.1 (72.1)	188.9 (63.3)	190.0 (69.5)
	Post S6 *	174.6 (60.0)	170.2 (61.3)	164.9 (41.8)	171.7 (57. 1)	70.4 (55.7)
Activation Level (%)	**Pre S1**	94.4 (4.2)	94.7 (3.4)	95.7 (2.9)	96.9 (1.34)	95.4 (3.3)
	Post S6 *	92.9 (3.9)	93.0 (4.8)	93.9 (3.9)	91.1 (6.6)	92.7 (5.0)
RMS (mV)	**Pre S1**	5.22 (1.28)	4.98 (1.54)	4.68 (0.98)	4.44 (1.43)	4.83 (1.36)
	Post S6 *	5.02 (1.14)	4.59 (1.51)	4.48 (0.99)	4.06 (1.46)	4.54 (1.34)
M-wave (mV)	**Pre S1**	10.4 (0.6)	10.3 (0.3)	9.9 (2.0)	11.0 (1.0)	10.4 (3.2)
	Post S6	10.1 (0.7)	10.8 (0.3)	9.2 (2.0)	10.8 (1.2)	10.2 (3.1)
Coactivation (%)	**Pre S1**	11. 8 (4.0)	12.9 (8.0)	12.7 (5.2)	13.5 (4.2)	12.7 (5.6)
	Post S6	11.6 (5.1)	12.8 (5.4)	11.5 (4.4)	11.2 (4.1)	11.6 (4.8)

Passive recovery (PR), active recovery (AR), stretching (ST), electromyostimulation (EMS). The last column represents an average of the four modalities values. Doublet peak torque (Pd), maximal voluntary contraction (MVC), activation level, root mean square (RMS), peak-to-peak amplitude of the M-wave (M-wave) and coactivation measured before (Pre S1) and after (Post S6) the isokinetic session. *: Significantly different from values Pre S1 ($p < 0.05$).

during the MVC plateau (superimposed doublet) as well as 1 s after the MVC (control doublet) to determine activation level according to the twitch interpolation technique (Merton, 1954).

Electromyography (EMG). EMG activity was recorded from vastus lateralis, vastus medialis, rectus femoris and biceps femoris muscles of the right thigh. Bipolar surface silver-chloride electrodes with a 2-cm inter electrode distance were used. After a careful preparation of the skin (shaving, abrading and cleaning with alcohol), electrodes were placed over muscles bellies. A reference electrode was placed on the patella. Myoelectrical signals were amplified with a bandwidth frequency ranging from 10 Hz to 2 kHz (common mode rejection ratio = 90 dB; impedance = 100 MΩ; gain = 500) and were digitized online at a 2 kHz sampling frequency.

Data analysis

Mechanical and myoelectric traces were digitized online and stored for analyses (Biopac sytems, Inc., MP System hardware and Acknowledge software). Peak torque was measured from the mechanical traces associated with paired stimuli (Pd) and MVC. Activation level (%) was calculated according to the twitch interpolation technique (Merton, 1954) using the following formula: activation level = (1-superimposed doublet/control doublet) ×100.

During the isokinetic session, an average of the torque of the first three and of the last three repetitions was calculated for sets 1, 3 and 6 in order to assess concentric fatigue time course (Michaut et al., 2003).

The amplitude of the EMG response to paired stimuli (M-wave) was measured. Muscular activity was quantified using root mean square values (RMS) calculated on a 500-ms period over the isometric plateau. RMS values were then normalized with respect to the M-wave amplitude. The level of coactivation was calculated by normalizing the RMS values of the biceps femoris when this muscle was acting as an antagonist to the RMS obtained when this muscle was acting as an agonist, that is, during knee flexion, and was expressed as a percentage (Lattier et al., 2004).

Statistical analysis

Data are presented as mean values ±SD. Since no difference was observed between the three extensor muscles, data presented throughout the manuscript for RMS and M-waves are the averages of those muscles. In the following analyses, modes corresponded to recovery modalities, time corresponded to pre and post values and sets was the comparison between Set 1, Set 3, and Set 6. Values were compared using a three-way ANOVA (modes × time × sets) using Statistica 8.0 (Statsoft Inc, Tulsa, USA). Then, Newman-Keuls post-hoc tests were used when significant main effects or interactions were obtained. Statistical significance was tested and accepted at $p < 0.05$. We assessed the inter-subject reliability with the intraclass correlation coefficient (ICC) and coefficient of variation (CV) using the first attempts during pre Set1 tests. The ICC indicates the error in measurements as a proportion of the total variance in scores. As a general rule, we considered an ICC over 0.90 as high, between 0.80 and 0.90 as moderate and below 0.80 as insufficient (Vincent, 1999). CV was interpreted with an analytical goal of 15% or below (Stokes, 1985). Statistical power values associated with the three-way ANOVA were automatically calculated for each variable. When statistical differences were found, power values were higher than 0.96.

Results

ICCs, measured for each variable were high, with values ranging from 0.97 to 0.99. Measurements reliability was good with CV ranging from 5.80 to 8.98 %. No adverse effects (pain or unpleasant sensation) were reported by the subjects during the four recovery procedures.

Pre Set 1 and post Set 6 values for all recorded parameters are shown in Table 1. All recovery modes confounded, a significant average decrease (time effect, $p < 0.05$) was obtained at the end of the isokinetic session for MVC (-8.8 ± 12.1%) and Pd (-8.0 ± 2.3%) as well as for RMS and activation level (-5.5 ± 14.2% and -2.7 ± 4.8%, respectively). M-wave amplitudes and coactivation were unchanged.

Set 1, Set 3 and Set 6 induced a significant strength decrease (peripheral fatigue) as shown by the diminution in Pd and MVC (Figure 2, $p < 0.05$) measured immediately after each set, but also by the torque developed during the last three repetitions of the set (Figure 3).

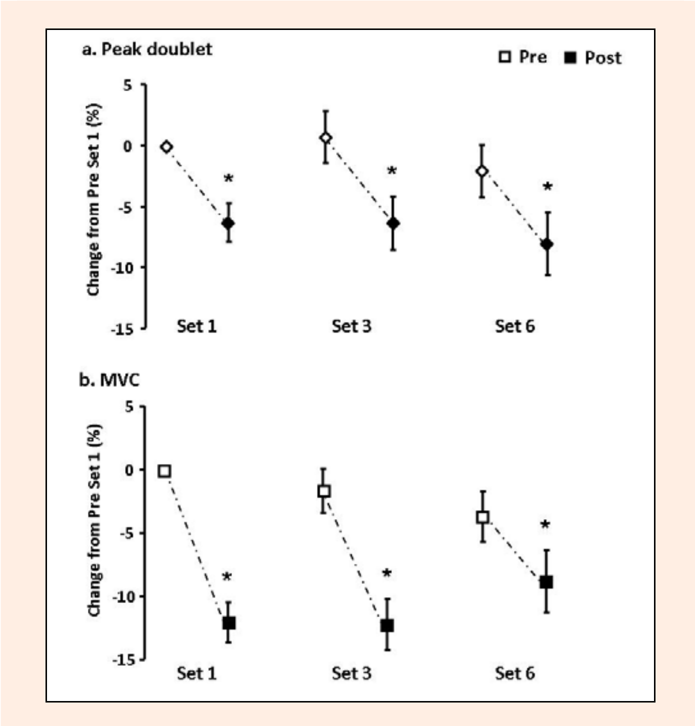

Figure 2. Average percentages of change from values measured before Set 1 (Pre S1) for peak doublet amplitude and maximal voluntary torque (MVC). S1: Set 1, S3: Set 3, S6: Set 6. Values are the average of the four recovery modalities. * Significantly different from pre S1 values ($p < 0.05$).

Central parameters (RMS, activation level and coactivation) were unaffected within the isokinetic session.

After three minutes of recovery, torque developed during dynamic voluntary contractions at the beginning of Set 3 and Set 6, was back to initial pre Set 1 values (Figure 3). There were no significant differences between passive recovery and the three recovery interventions.

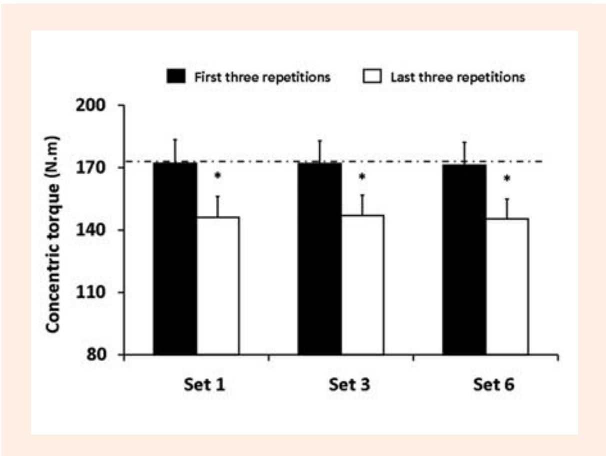

Figure 3. Mean torque developed during the first three and the last three concentric contractions of Set 1, Set 3 and Set 6. Values are the average of the four recovery modalities. Significant differences between pre and post for a given set (* $p < 0.05$).

Discussion

These data provide insight to the effects of between-set interventions on changes in muscle function over six sets of ten maximal isokinetic concentric contractions of the knee extensors. We found that peripheral parameters were firstly altered while central fatigue appeared only at the end of the session. Recovery interventions between sets did not modify fatigue time course as compared with passive recovery.

Several mechanisms, such as neuromuscular propagation, excitation-contraction coupling, intracellular regulation, might be responsible for the decreases observed in evoked contractions and MVC (Bigland-Ritchie, 1984; Hill et al., 2001). However, the absence of any modification of the M-wave amplitude showed that peripheral fatigue can not be attributed to a modification of neuromuscular propagation. Conversely, the observed Pd reduction indicated an altered excitation-contraction coupling, and therefore suggested perturbations of intracellular regulation (Hill et al., 2001) that controls cross-bridges kinetic, number, and force (Lamb, 2000). While unchanged throughout the isokinetic session, the activation level and RMS were significantly decreased after the sixth set. These results suggested that at the end of the isokinetic session, both central and peripheral fatigue contributed to the observed MVC decreases. Comparable decreases in MVC, Pd and activation level have previously been found after a similar isokinetic exercise (Zory et al., 2010). Central fatigue may originate from supraspinal and/or spinal factors, i.e. central motor drive, motoneurons excitability and neuromuscular transmission (Bigland-Ritchie, 1984). According to Gandevia (2001), central changes occur at a spinal level due to the altered input from muscle spindle, tendon organ, and group III and IV muscle afferents innervating the fatigued muscles. A similar fatigue time course, i.e. peripheral alterations followed by central ones, has previously been found (Babault et al., 2006). These authors concluded that fatigue time course was dependent upon muscle contractile conditions with inverse time courses being observed between exercises involving concentric vs. isometric contractions. Surprisingly, despite an additional central fatigue at the end of the session session, MVC was not further decreased in comparison with post Set 1 and post Set 3. This may be explained by the non-linearity of the EMG-force relation: great changes in EMG are necessary to induce significant changes in MVC (Rabita et al., 1994).

Regarding fatigue time course, our results also showed that torque values (doublets and MVC) registered after recovery periods were back to their initial values, whatever the interventions. This suggests that the three minutes separating sets allowed the subjects to fully recover both in passive condition and with recovery interventions. The results are quite surprising since we initially hypothesized that recovery intervention would be more effective than passive recovery. Indeed, these methods, and more particularly bicycle and electromyostimulation, are known to favour blood flow (Gupta et al., 1996) and therefore metabolites washout and/or lactate clearance. However, our results did not show any difference between the four modalities. In the literature, both similar and opposite results are reported. For example, Lau et al. (2001) concluded that active recovery did not enhance lactate removal or subsequent performance in simulated hockey games and Toubekis et al. (2005) suggested that passive recovery was the most appropriate to maintain a high intensity during repeated swimming sprints of short durations. Conversely, other experiments showed that active recovery is more effective than passive recovery, notably between sprint repetitions on ergocycle (Bogdanis et al., 1996; Signorile et al., 1993). Several parameters seem to be important when studying the effects of different recovery modalities on fatigue kinetics and could explain the diversity of the reported results. Among them, we can cite the exercise characteristics (type, muscle mass involved, intensity, duration), the duration of recovery periods but also the time when recovery is applied (during or after the exercise). The absence of any difference between recovery interventions and passive recovery in the present study might be explained by the fact that the exercise was not long or intense enough to really fatigue subjects (muscle mass involved, angular velocity). Also, the positive effect of recovery on the stimulus intensity in the present study (no significant decreases in the pre-set values over 6 sets) could be only attributable to the relatively long recovery duration (3 minutes) and not to the modality applied. Results might be different with shorter between-sets intervals (2 minutes) and therefore shorter recovery interventions. However, one could argue that applying recovery interventions during such short periods might be complicated and induce additional fatigue rather than favour recovery.

Conclusion

The results of the current study showed that exercises composed of 6 sets of 10 concentric maximal contractions induce a progressive fatigue with peripheral alterations occurring first followed by central ones. Also, the three minutes of recovery between sets allowed the subjects to start each new set with torque values similar to those from the beginning of the session. Recovery interventions of different types (light pedalling, stretching or electromyostimulation) did not modify fatigue time course as compared with passive recovery. This suggests that there is no need to apply complicated recovery modes between sets during this type of isokinetic session, passive is enough. Further studies using exercises designed to induce a greater fatigue should be conducted in order to know more about the effects of different recovery modalities applied between sets.

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Key points

- Allowing three minutes of recovery between sets of 10 maximal concentric contractions would help the subjects to recover from the peripheral fatigue induced by each set and therefore to start each new set with a high intensity.
- During this type of session, with three minutes between sets, passive recovery is sufficient; there is no need to apply complicated recovery interventions.

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