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Disturbed motor control of rhythmic movement at 2 h and delayed after maximal eccentric actions

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ABSTRACT

The aim of this study was to examine the influence of exercise-induced muscle damage on elbow rhythmic movement (RM) performance and neural activity pattern and to investigate whether this influence is joint angle specific. Ten males performed an exercise of 50 maximal eccentric elbow flexions in isokinetic machine with duty cycle of 1:15. Maximal dynamic and isometric force tests (90°, 110° and 130° elbow angle) and both active and passive stretch reflex tests of elbow flexors were applied to the elbow joint. The intentional RM was performed in the horizontal plane at elbow angles; 60–120° (SA-RM), 80–140° (MA-RM) and 100–160° (LA-RM). All measurements together with the determination of muscle soreness, swelling, passive stiffness, serum creatine kinase were conducted before, immediately and 2 h as well as 2 days, 4 days, 6 days and 8 days post-exercise. Repeated maximal eccentric actions modified the RM trajectory symmetry acutely (SA-RM) and delayed (SA/MA/LA-RM) until the entire follow up of 8 days. Acutely lowered MA-RM peak velocity together with reduced activity of biceps brachii (BB) at every RM range, reflected a poorer acceleration and deceleration capacity of elbow flexors. A large acute drop of BB EMG burst amplitude together with parallel decrease in BB active stretch reflex amplitude, especially 2 h post-exercise, suggested an inhibitory effect originating most likely from groups III/IV mechano-nociceptors.

1. Introduction

Significance of the peripheral feedback in the control of rhythmic movement has received more attention only recently. As the muscle proprioception is well known to contribute to position and movement sense (e.g. Roll et al., 1989), the proprioceptive feedback has been shown to be necessary in order to maintain the non-preferred rhythmic movement stationary (Bonnard and Pailhous, 1999). The absence of this feedback may affect the fine control of antagonistic muscles activity (Nicol et al., 1997) and cause instantaneous fluctuations in rhythmic movement amplitude and frequency (Bonnard and Pailhous, 1999). In line with the findings of impaired position, (Saxton et al., 1995; Brockett et al., 1997) and force senses (e.g. Carson et al., 2002), and a reduced ability to discriminate movement velocity (Pedersen et al., 1999) the eccentric muscle actions have been shown to modulate the antagonistic muscles timing and activity pattern of both rhythmic (Bottas et al., 2009) and target movement (Bottas et al., 2005).

In the rhythmic movement the antagonistic muscles show reciprocal activity (e.g. Feldman, 1980; Bottas et al., 2009) and in the fastest movements the reciprocally activated muscles are nearly totally out of phase (Bottas et al., 2009). Overlapping co-activity phases are also present (e.g. Feldman, 1980; Nicol et al., 1997; Bottas et al., 2009) which seem to be dependent on antagonistic muscles activity turn i.e. on the reciprocal activation order (Bottas et al., 2009). In this respect, the control of elbow antagonistic muscle pair is under the reciprocal Ia inhibition (Katz et al., 1991) shown to be dependent on both the antagonistic muscles activity turn and the joint angle (McClelland et al., 2001).

The segmented activity of a muscle has been shown to be typical for the rhythmic movement activity pattern (Bottas et al., 2009). In a stretch shortening cycle (SSC) type performance (Komi, 1984), as can the rhythmic movement be considered as well, the reflex potentiation which strengthen the muscle activation manifests itself as a segmented activity pattern (e.g. Dietz et al., 1981; Gollhofer et al., 1987; Nakazawa et al., 2001). In SSC muscle action the early muscle activity to brake the antagonistic movement will store elastic energy in muscle tendon complex which gives possibilition for the utilization of elastic energy for the following agonist movement acceleration phase. Through the recoil the potentiated activity contributes to force production (e.g. Cavagna, 1977; Komi and Gollhofer, 1997). The amount of this reflex assistance will depend on the level of ongoing voluntary

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activity (e.g. Marsden et al., 1976; Matthews, 1986), the load and velocity of active stretch (e.g. Stein et al., 1995; Nakazawa et al., 2001) and the muscle length or joint angle (Yamamoto et al., 2000; McClelland et al., 2001). Based on the main contribution of the stretched muscles to the position acuity (e.g. Roll et al., 1989) exercise-induced reduction of muscle proprioception could result in modification of muscles segmented activity pattern.

Eccentric exercise causes reductions in maximal static (e.g. Clarkson et al., 1992; Sbriccoli et al., 2001) and maximal dynamic actions that may last for several days (Bottas et al., 2009) or even for weeks (Faulkner et al., 1993; Sayers and Clarkson, 2001). Reduced post-exercise force production has been associated with a right shift of the active length–tension relation (e.g. Saxton and Donnelly, 1996; Jones et al., 1997). Additional muscle injury related mechanical symptoms such as swelling, reduced range of motion (e.g. Clarkson et al., 1992) and increased passive stiffness (e.g. Howell et al., 1993) may affect dynamic performances for several days. The sequence of exercise-induced muscle damage events has been postulated to include initial and secondary structural injury phases associated with progressive inflammatory/regenerative process and muscle soreness 2–4 days post-exercise (e.g. Faulkner et al., 1993; Clarkson and Newham, 1995; Lieber and Fridén, 2002). Muscle pain together with the overall recovery process from exercise-induced muscle damage is very likely to affect muscle activation both at supraspinal and spinal levels during the acute and delayed recovery phases (review of Gandevia (2001)).

Our earlier findings of post-exercise central adaptations of maximal velocity elbow movements activity patterns were suggested to be related to III and IV muscle afferents increased sensitivity due to both acute metabolic (Bottas et al., 2005) and delayed inflammatory substances within the damaged muscles (Bottas et al., 2009). Their influence on neural activation at different levels of the nervous system have been reported to be both facilitatory and inhibitory, however, some indirect evidence favour the presynaptic inhibitory effect on alpha-motoneurons (e.g. Garland and McComas, 1990). According to recent study of Martin et al. (2006) on elbow muscles, inputs of small muscle afferents from homonymous or antagonist muscles would vary among muscles, with the trend to inhibit extensor motoneurons and to facilitate flexor ones. In line with this the reciprocal activity of rhythmic movement has been found to be modified showing delayed increment of flexor activity after the eccentric exercise (Bottas et al., 2009). However, compensation in rhythmic task may take place in the fatigued flexor muscle only as acute responses were not observed similarly to Martin et al. (2006) during the isometric metabolic fatigue.

In our previous study with an eccentric fatigue protocol both the metabolic and muscle damage factors were influencing the acute fatigue effects (Bottas et al., 2009). In the present study eccentric exercise protocol of elbow flexors was arranged in such a way (duty cycle of 1:15) that acute metabolic fatigue and acidosis were avoided and only the effects of muscle damage were expected to appear. Since the eccentric fatigue and damage are known to influence proprioception, the purpose of the present study was to examine both acute and delayed influences of exercise-induced muscle damage (peripheral disturbance) on elbow rhythmic movement performance and on neural activity pattern (central adaptations). More specifically an acute decrease of flexor activity connected to long-term performance drop was hypothesized. Since the proprioceptive feedback has been regarded as relevant to modulate muscles neural activity of fast elbow movements the special emphasis was put on the dissection of the congruence between biceps brachii activity pattern in rhythmic movement and its stretch reflex activity.

2. Methods

2.1. Subjects

Ten physically healthy right handed males volunteered for this study. The selection criteria were above-mentioned as all testing apparatus were designed to right handed and because the neuromuscular system of a subject had to be intact. The subjects' mean age, height, body mass, and body fat were 25.3 (SD: 1.7) years, 179.3 (SD: 7.4) cm, 78.0 (SD: 7.0) kg, and 15.8 (SD: 3.3)%, respectively. The study was conducted according to the declaration of Helsinki and was approved by the ethics committee of the University of Jyväskylä, Finland. The subjects were aware of the study ethics and possible risks and discomfort of the study protocol and they all gave their written informed consent to participate. The subjects were not allowed to perform physically heavy activities acutely before and during the study period.

2.2. Exercise protocol

After a detailed instruction and warm-up trials of the eccentric muscle actions, the subject performed 50 maximal eccentric elbow flexions with an isokinetic (constant velocity) machine (Komi et al., 2000). The subject sat at the machine and his forearm was fixed in a supinated position to the specific wrist cuff of the lever arm. The axis of machine lever arm corresponded to the rotational axis of the right elbow joint. The force applied to the wrist for elbow flexion resisting the machine lever arm movement was measured by a strain gauge transducer. The movement range during eccentric exercise was from 50° to 170°, wherein 180° position indicates full elbow extension. The angular velocity was 2 rad s^{-1}. Thus, one repetition lasted about 1.05 s. All actions were performed at 15 s intervals (duty cycle of 1:15). During this time period the forearm was passively returned back to 50° starting angle and approximately 0.5 s of it was used for maximal isometric pre-activation for the next repetition. The subject was repeatedly encouraged to perform each action with maximal effort. The total exercise duration averaged about 13 min with about 1 min 20 s of actual work.

2.3. Testing protocols

2.3.1. Maximal isometric and eccentric force

The force of maximal isometric action (MIA) was tested at 90°, 110° and 130° elbow angles followed by the test of eccentric force. The force of last maximal eccentric action (MEA; elbow range 50–170°) of the exercise was taken as an immediately post-exercise value. The force of MEA and MIA (including one or two actions per test situation in order to record force of maximal performance) were tested before, immediately after, 2 h, 2 days, 4 days, 6 days and 8 days after maximal eccentric exercise.

2.3.2. Stretch reflex measurements

Active and passive stretch reflex tests on elbow flexors were performed with the same machine as the exercise. Stretches of 20° amplitude with 0.110 s stretching time – 4 rad s^{-1} velocity and 100 rad s^{-1} acceleration – were applied to elbow at six joint angles; 50°, 70°, 90°, 110°, 130° and 150°. A pre-stretch force of 20%/MIA (maximal isometric force at that test point) was used in "active" stretch reflex tests. The subject was informed to maintain the constant force – which he saw from the oscilloscope screen – throughout the stretch perturbation. In the passive reflex test a subject was blindfolded and he was informed to keep the forearm relaxed. The stretches were applied with irregular intervals of 5–10 s starting from the most flexed joint position. The order of passive and active tests was kept always the same starting out by the passive test.