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Letter to editor

Maximal Voluntary Co-Contraction Training May Not Always be Effective for Some Leg Muscles

Dear Editor-in-Chief

Simultaneous voluntary contractions of antagonistic pairs (co-contraction) produce resistive forces that act against each other (Maeo et al., 2013c). It has been reported that a training program in which subjects performed voluntary co-contractions of elbow flexors and extensors with maximal effort produced significant increases in the strength capability of both muscle groups, without the use of an external load as resistance (Maeo et al., 2013c). In addition, the level of their muscular activities during the task, expressed as the value relative to those during maximal voluntary contraction (MVC) of corresponding muscles (% EMGmax), has been shown to be a sufficient training stimulus (~40% for elbow flexors and ~60% for elbow extensors) for improving the strength capability of both muscle groups (Maeo et al., 2013c). Thus, it is considered that maximal voluntary co-contraction can be an effective form of resistance raining. However, the muscle groups examined previously are limited to the elbow flexors and extensors. It is known that the influence of aging on muscle mass is more apparent in the lower body than in the upper body (Janssen et al., 2000), and the antigravity muscles located in the lower extremity have a greater influence of decreased mechanical loading conditions such as bed rest, limb immobilization, and space flight (Kanehisa, 2005). To establish the efficacy of the co-contraction training, therefore, it is essential to clarify the muscle activation levels of lower limb muscles during the co-contraction tasks.

In the task which requires maximal voluntary co-contractions of the upper arm muscles, stronger elbow flexors would need only to be activated to the extent to which they cancel the torque produced by weaker elbow extensors, resulting in a lower activation level in the elbow flexors than in the extensors during the task (Maeo et al., 2013a, c). On the other hand, in leg muscles, it is often reported that there are large differences in maximal strength between muscles in the antagonistic pairs (e.g. the knee extensors/flexors pair as well as the plantar flexors/dorsi flexors pair) (Billot et al., 2010; Macaluso et al., 2002). Thus, theoretically, it is assumed that during maximal voluntary co-contraction in the leg muscles, the stronger side of the muscle groups (i.e. knee extensors and plantar flexors) result in much lower level of the muscular activity than the weaker side (i.e. knee flexors and dorsi flexors). The present study aimed to clarify this by comparing the muscular activity levels of the leg muscles in antagonistic pairs during maximal voluntary co-contraction task. The results of this study may provide useful information concerning the efficacy of maximal voluntary co-contraction training for the leg muscles.

Ten young males participated in this study. The means and SDs of age, body height, and body mass in the subjects were 22.2 ± 1.5 yrs, 1.70 ± 0.04 m, and 64.2 ± 4.2 kg, respectively. The measurement was performed on the right leg. Firstly, the participants performed isometric MVC tasks. Torque during MVC was measured using a force-measurement device with tension/compression load cells (LUR-A-SA1; Kyowa, Tokyo, Japan). In the MVC tasks, as well as subsequent maximal voluntary co-contraction tasks, the EMG activities of knee extensors (rectus femoris and vastus lateralis, averaged), knee flexors (biceps femoris), plantar flexors (gastrocnemius and soleus, averaged), and dorsi flexors (tibialis anterior) were also recorded. After a process of sufficient warming-up and a rest period, the subjects performed MVCs of knee extension, knee flexion, plantar flexion, and dorsi flexion for 5 s twice for each task with at least 3 min between trials. In the knee extension/flexion MVC tasks, the subjects were seated in an adjustable chair with support for the back, shoulders, and hips. With the hip joint and knee joint angle at 90 deg (180 deg = full extension), the subjects performed the MVCs. In the plantar flexion/dorsi flexion MVC tasks, the subjects were seated in an adjustable chair with support for the back and hips. With the hip joint angle at 90 deg, knee joint angle at 180 deg, and foot joint angle at 90 deg, the subjects performed the MVCs. Additional trials were performed if the differences in the peak torques of the two MVCs of each task were more than 5%. The trial with the highest peak torque was selected for analysis.

After the completion of MVC tasks, the subjects performed maximal voluntary co-contraction tasks for 5 s twice for each of the knee extensors/flexors pair and the plantar flexors/dorsi flexors pair with at least a 3-min interval. The postures for maximal voluntary co-contraction tasks were the same as for the MVC tasks of each muscle pair, but the force-measurement device was removed so that the subjects could extend/flex their knee joint and plantar flex/dorsi flex their foot joint without restriction. An examiner visually checked the subjects' posture during the tasks to ensure that there were no joint movements.

For the EMG measurements, we followed the previous guidelines for electrode locations (Hermens et al., 1999), and used the same measurement device (Maeo et al., 2013c) and the process of data analysis (Maeo et al., 2013a, c) as described elsewhere. Briefly, in the MVC task, the maximum value of EMG (EMGmax) in each agonist muscle was determined over a 500 ms window centered on the time at which peak torque was attained. In the maximal voluntary co-contraction task, EMG data during the middle 3 s of maximal effort (5 s) were analyzed in each muscle and averaged across two trials, and EMGs of each muscle during the maximal voluntary

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co-contraction task are expressed as the value relative to those during MVC of each muscle (% EMGmax). A paired Student's t-test was used to test the difference between muscles in the antagonistic pairs (e.g. knee extensors vs. knee flexors) in maximal torque during MVC and muscular activity level during maximal voluntary co-contraction task. Statistical significance was set at $p < 0.05$. All data were analyzed using SPSS software (SPSS Statistics 20; IBM, Japan).

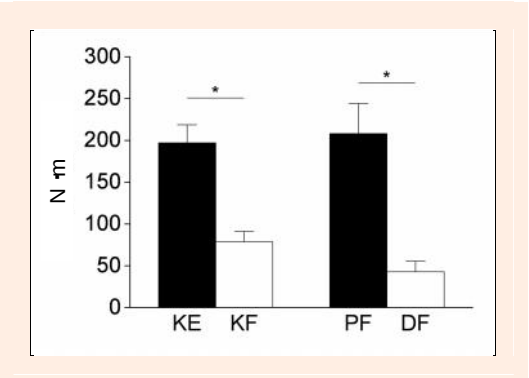

Figure 1. The maximal torques during MVC of knee extension (KE), knee flexion (KF), plantar flexion (PF), and dorsi flexion (DF). Values are means ± SDs. * indicates significant difference between muscles in antagonistic pairs ($p < 0.05$).

In the MVC task, maximal torque was significantly higher in knee extension than in knee flexion, as well as significantly higher in plantar flexion than in dorsi flexion (Figure 1). In the maximal voluntary co-contraction task, muscular activity level was significantly lower in knee extensors than in knee flexors, as well as significantly lower in plantar flexors than in dorsi flexors (Figure 2).

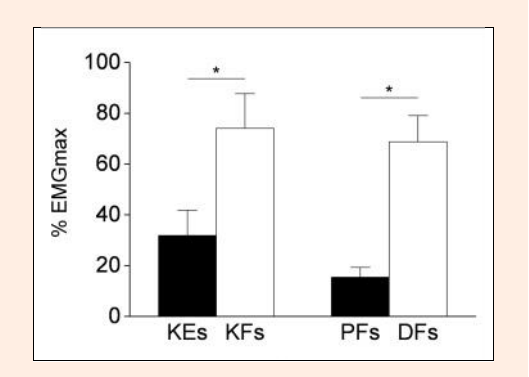

Figure 2. The muscular activity levels in knee extensors (KEs), knee flexors (KFs), plantar flexors (PFs), and dorsi flexors (DFs) during maximal voluntary co-contraction task. Values are means ± SDs. * indicates significant difference between muscles in antagonistic pairs ($p < 0.05$).

As has been previously reported (Billot et al., 2010; Macaluso et al., 2002), significant and large difference was found in maximal torque between knee extension and flexion as well as between plantar flexion and dorsi flexion. Consequently, as expected, the muscular activation levels during maximal voluntary co-contraction tasks were significantly lower in the stronger side of each pair (i.e. knee extensors and plantar flexors) than in the weaker one (i.e. knee flexors and dorsi flexors). This supports the aforementioned theory that muscular activation level during maximal voluntary co-contraction depends on the difference in maximal strength between muscles in an antagonistic pair (Maeo et al., 2013c).

To the authors' knowledge, no study has examined muscular activation level during maximal voluntary co-contraction in leg muscles. However, in the upper arm (Maeo et al., 2013a, c) and abdominal (Maeo et al., 2013b) muscles, it has been shown that none of the muscles can be fully activated under the condition of maximal voluntary co-contraction. As possible factors limiting maximal activation in antagonistic muscles during co-contraction, the influences of inhibitory systems occurring at both central and peripheral sites, such as dual-task interference and Ia reciprocal inhibition as well as recurrent inhibition might be considered (Maeo et al., 2013a, b, c). In any case, the relatively low activation levels in the knee extensors (31.9 ± 10.0%) and especially in the plantar flexors (15.4 ± 3.9%) suggest that maximal voluntary co-contraction training may not always be effective for those muscles.

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