Journal of Electromyography and Kinesiology 24 (2014) 895–901

Contents lists available at ScienceDirect

Journal of Electromyography and Kinesiology

journal homepage: www.elsevier.com/locate/jelekin

Increase in rate of force development with skin cooling during isometric knee extension

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ARTICLE INFO

Article history:
Received 6 March 2013
Received in revised form 22 July 2014
Accepted 15 August 2014

Keywords:
Cutaneous input
Cold receptors
Skin temperature
Electromyography
Quadriceps

ABSTRACT

Rate of force development (RFD) plays an important role when performing rapid and forceful movements. Cold-induced afferent input with transient skin cooling (SC) can modulate neural drive. However, the relationship between RFD and SC is unknown. The purpose of this study was to investigate whether SC increases RFD during isometric knee extension. Fifteen young healthy men (25 ± 8 yrs old) contracted their quadriceps muscle as fast and forcefully as possible with or without SC. Skin cooling was administered to the front of the thigh. Torque and electromyographic activity were measured simultaneously. Peak torque was not affected by SC. Skin cooling induced a significant increase in RFD at the phase 0–30 and 0–50 ms. The root mean square of the electromyography of vastus medialis, rectus femoris and vastus lateralis at the phases 0–30–50–100 ms increased significantly or tended to increase with SC. These results suggest that SC may increase neural drive and improve RFD in the very early phases of contraction.

1. Introduction

An initial force response, which is called rate of force development (RFD), obtained from the slope of force–time curve during maximal or high intensity contraction, provides important information on neuromuscular function (Girard and Millet, 2009). Rate of force development is affected by neural drive (Aagaard et al., 2002; Barry et al., 2005; Klass et al., 2008), distribution of myosin heavy chain isoform (Korhonen et al., 2006), muscle cross sectional area (Suetta et al., 2004), and the stiffness of the tendinous structure (Bojsen-Moller et al., 2005; Reeves et al., 2003). Especially, increasing neural drive is an important factor in improving RFD (Aagaard, 2003). Additionally, RFD influences performance in daily life activities such as walking speed in elderly people after hip-replacement surgery (Suetta et al., 2004) and in sporting activities such as jumping height (judging from impulse in the force developing phase which is equivalent to RFD (de Ruiter et al., 2006)) and RFD is also related to balance performance (one leg standing and tandem gait) in older adults (Chang et al., 2005). An increase in RFD is reflected by increasing EMG activity. Rate of force development plays a role in the ability to perform rapid and forceful movement (Aagaard, 2003). Therefore, increasing RFD, which relates to greater torque within a shorter time to overcome inertia, is necessary for improving walking speed and jumping height or distance.

Many studies suggest that dynamic training (30–40% maximal voluntary strength performed as fast as possible) (Van Cutsem et al., 1998) and high intensity resistance training at an intensity of more than 70% maximal voluntary contraction (Aagaard et al., 2002; Del Balso and Cafarelli, 2007; Holtermann et al., 2007), lead to improved RFD. Additionally, maximal slow-speed (30 deg s^{-1}) concentric training and eccentric training also lead to improved RFD (Blazevich et al., 2008). However, low intensity resistance training at an intensity of 30% maximal voluntary contraction, seems to have little effect on RFD (Schmidtbleicher and Haralambie, 1981). This implies that the improvement of RFD relies on the earlier recruitment of high threshold motor units (HT-MUs), which makes a greater contribution to force output than

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http://dx.doi.org/10.1016/j.jelekin.2014.08.002
1050-6411/

low threshold MUs (LT-MUs), and on an increase in MU discharge rate including synchronization and doublet discharge (Del Balso and Cafarelli, 2007). Holtermann et al., 2007 reported that an increase in RFD with resistance training was associated with changes in H-reflex amplitude, a factor which represents the excitability of motor neurons. Therefore, increasing the excitability of motor neurons has the potential to improve RFD.

Cutaneous input can change motor unit recruitment threshold and firing rate (Masakado et al., 1991). Some studies have reported that skin cooling (SC), which is a kind of the cutaneous input, induced by the cold environment or cold air, with minimal change of muscle temperature, enhances muscle activity (Rissanen et al., 1996, Winkle and Jorgensen, 1991, Yona, 1997). Yona (1997) reported that SC induced high threshold motor unit recruitment earlier in ramp contraction. Moreover, some studies have reported that SC increases excitability in motor neurons (Dewhurst et al., 2005; Oksa et al., 2002). Dewhurst et al. (2005) reported that H-reflex output was facilitated in the cooling condition among young individuals. It has also been suggested that muscle activity decreases in cold muscle (Oksa et al., 1995, Petrofsky and Lind, 1980). Taken together, these studies have clarified that SC (facilitating the input from skin cold receptors), with a small decrease in muscle temperature, modulates the excitability of motor neurons.

As alluded to above, SC contributes beneficially to force output due to an increase in motor neuron excitability. However, there have been no studies investigating the effects of SC on RFD. Therefore, the purpose of this study was to investigate the effect of SC on RFD in the quadriceps muscle. We hypothesized that SC increases motor neuron excitability and improves RFD in the early phase of voluntary contraction.

2. Methods

2.1. Subjects

Fifteen healthy men (age 25 ± 8 yrs, height 172 ± 7 cm, weight 63 ± 10 kg, means ± SD) participated in this study which was performed in accordance with the Declaration of Helsinki. The study was explained to all subjects, and they were familiarized with the procedure, at an orientation session after which they gave their written informed consent. This study was approved by the Toho University Ethics Committee.

2.2. Measurement of maximal muscle strength and RFD

Maximal quadriceps muscle strength was measured as maximal isometric knee extension on the dominant (right) side. As shown in Fig. 1, subjects sat in an adjustable chair-like device and their right lower leg was attached to a plate connected to a torque meter (type 9E05-B1-50, NEC, Tokyo, Japan). The hip and distal lower leg were bound and fixed in order to minimize the movement of hip extension. Subjects were allowed to firmly grip the edges of the chair to stabilize their trunk. Maximal isometric knee extension was performed at a knee joint angle of 60 deg of flexion (0 deg is full extension) and at a hip angle of 80–90 deg of flexion. Knee angle was determined with a goniometer using anatomical landmarks (trochanter major femoris, epicondylis lateralis, and malleolus lateralis on the fibula) as reference points. After warming up (a number of submaximal and maximal preconditioning trials), subjects performed three to four maximal isometric knee extensions with the instruction: “as fast and forcefully as possible”. Verbal encouragement was provided by investigators when subjects contracted knee extensors. Trials where a ‘torque drop’ was observed as a torque below zero before the onset of contraction (counter movement) were disqualified and another trial was

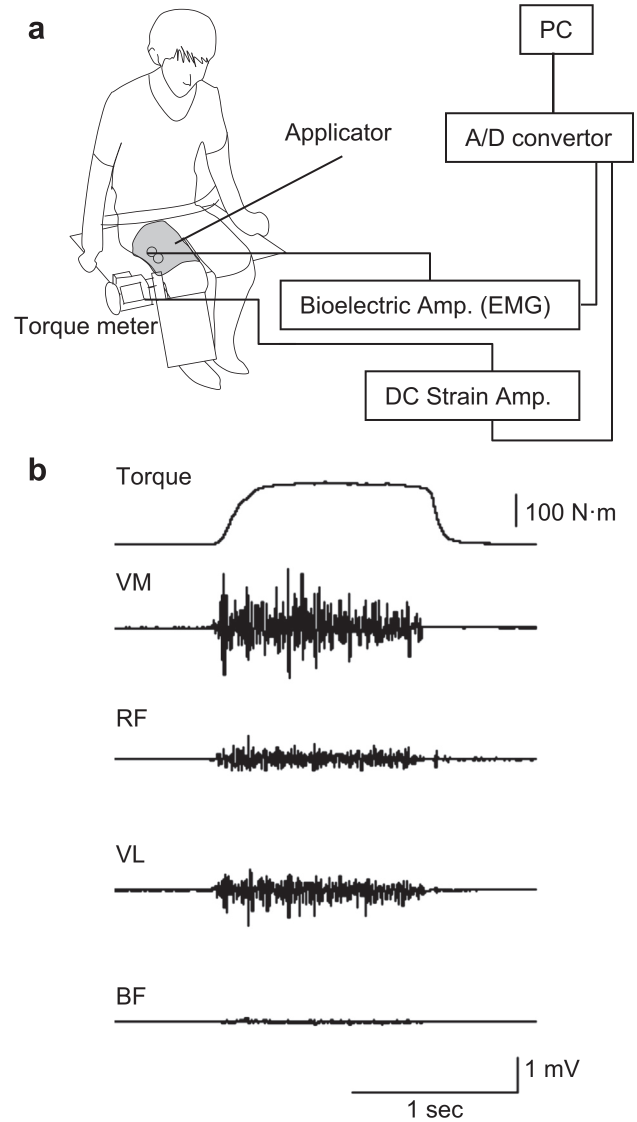

Fig. 1. Experimental setup in this study (a) and a sample of raw data (b). Subjects sat on an adjustable chair-like device and the lower leg was attached to a plate connected to a torque meter. The sample of raw data represents torque, surface electromyography (EMG) of vastus medialis (VM), rectus femoris (RF), vastus lateralis (VL) and biceps femoris (BF), from the top, respectively.

performed. This procedure was carried out randomly with SC or without SC (CON). Torque was measured at a sampling rate of 1000 Hz and smoothed by using a cutoff frequency of 15 Hz in later analysis (Aagaard et al., 2002).

Rate of force development was derived as the slope of initial time–torque curve (torque/time) at 30, 50, 100, and 200 ms relative to the onset of contraction. Peak RFD was defined as the peak value of a differentiation between torque and time (dT/dt). Onset of contraction was defined as the instant where torque exceeded 7.5 N m (Aagaard et al., 2002).

2.3. Electromyography recording

Surface electromyography (EMG) was measured from vastus medialis (VM), rectus femoris (RF), vastus lateralis (VL) and biceps femoris (BF) using bipolar electrodes (10 mm diameter, and 20 mm interelectrode distance) as shown in Fig. 1. After careful preparation of the skin (shaving and abrasion with sand paper), the electrodes were placed on the aforementioned muscles and fixed in position with surgical tape. A reference electrode was placed