



Electromyogram and force fluctuation during different linearly varying isometric motor tasks

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ARTICLE INFO

Article history:

Received 13 February 2010

Received in revised form 12 March 2010

Accepted 17 March 2010

Keywords:

EMG

FDI

Motor units activation strategy

Linearly varying isometric contractions

ABSTRACT

The purpose of this work was to verify if deviation from the mirror-like behaviour of the motor units activation strategy (MUAS) and de-activation strategy (MUDS) and the degree of the error of the motor control system, during consecutive linearly increasing–decreasing isometric tension tasks, depend on the maximum reached tension and/or on the rate of tension changes. In 12 male subjects the surface EMG and force produced by the first dorsal interosseus activity were recorded during two (a and b) trapezoid isometric contractions with different plateau (a: 50% maximal voluntary contraction (MVC) and b: 100% MVC) and rate of tension changes (a: 6.7% MVC/s and b: 13.3% MVC/s) during up-going (UGR) and down-going (DGR) ramps. Ten steps (ST) 6 s long at 5, 10, 20, 30, 40, 50, 60, 70, 80 and 90% MVC were also recorded. The root mean square (RMS) and mean frequency (MF) from EMG and the relative error of actual force output with respect to the target (% ERR) were computed. The EMG-RMS/% MVC and EMG-MF/% MVC relationships were not overlapped when the ST and DGR as well as the UGR and DGR data were compared. The % ERR/% MVC relationships during a and b contractions differed from ST data only below 20% MVC. It can be concluded that MUAS and MUDS are not mirroring one each other because MU recruitment or de-recruitment threshold may be influenced by the maximum effort and by the % MVC/s of UGR and DGR. The role of MUs mechanical and/or central nervous system hysteresis on force decrement control is discussed.

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1. Introduction

Specific modulation of the muscle output force is obtained by the motor units (MU) recruitment and firing rate scheme (Basmajian and De Luca, 1985) adopted by the central motor control program. The activation of a single MU by the central nervous system provides a train of motor unit action potentials (MUAPT) with a mechanical counterpart at the tendon. This last is the motor unit force fluctuation (MUFF) around an average value (Taylor et al., 2003). When different MUs are active the single MUAPTs and MUFFs summate in the interferential surface electromyogram (EMG) (Basmajian and De Luca, 1985) and in the overall force fluctuation (FF) at the tendon (Taylor et al., 2003), respectively. The time and frequency domain analyses of the two signals may provide information about the motor unit activation strategy encompassing the number of active MUs, their firing rate, the degree of synchronization of the different MUs discharges, though all these contributors may be biased by the location of the MU territory, its specific conduction velocity (CV) and other features of the

MUs (Basmajian and De Luca, 1985; Farina et al., 2002; Taylor et al., 2003). With these limitations in mind it can be assumed that the increase of EMG mean frequency (MF), as a function of the isometric effort, may reflect the recruitment (REC) from smaller to larger MUs, with higher CV. This REC pattern may be tracked by EMG-MF/effort level relationship when specific anatomical and geometrical constrains, as the more superficial distribution of the large fibre type MUs, are satisfied (Solomonow et al., 1990; Farina et al., 2002, 2004a). Indeed Bernardi et al. (1996) reported, for increasing isometric effort from low to maximal voluntary contraction (MVC), an increase of the EMG-MF until REC of MUs with larger CV took place and then a plateau when firing rate (FR) coding was used to reach the desired target force. On the contrary EMG root mean square (RMS) that is both influenced by REC and FR is well known to increase up to the MVC (Basmajian and De Luca, 1985; Farina et al., 2004b). In summary, EMG-RMS and EMG-MF may be used to track the REC and FR modulation as a function of the requested muscle tension output (expressed as % MVC, in other words as a function of the MU activation strategy (MUAS)).

Similarly to EMG, FF can be considered as an interferential signal where the force oscillations of each active MU are summated. Indeed, according to Marshall and Walsh (1956) FF can be regarded

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as the outcome of the asynchronous discharge of motor nerve fibres “converted to mechanical ripples by the muscles”. On this basis its time and frequency domain analyses can provide data about the MUs activation scheme adopted by the central nervous system (Homberg et al., 1986; Elble et al., 1996; Bilodeau et al., 2009).

During voluntary contraction REC takes place according to the Hennemann size principle that gives a specific recruitment threshold to each MU corresponding to a given % MVC. Indeed it seems that MUs have a dynamic threshold too, corresponding to the velocity (% MVC/s) of the output tension changes (Freund, 1983). Moreover the motor units de-activation strategy (MUDS) has not been widely investigated even if some data suggest that differences between the recruitment and de-recruitment thresholds (De Luca et al., 1982; Spiegel et al., 1996; Patten and Kamen, 2000) as well as between the FR at the same effort level, during increasing or decreasing isometric effort, may exist (Milner-Brown et al., 1973b; De Luca et al., 1982; Denier van der Gon et al., 1985). In particular MUDS changes as a function of the velocity of linear tension decrease have not been described.

On these basis the work is aimed to characterize:

- MUAS and MUDS by means of EMG-RMS/% MVC and EMG-MF/% MVC relationships.
- The unsteadiness of the motor output by means of the force error/% MVC relationship during different motor tasks such as up-going (UGR) and down-going (DGR) consecutive isometric ramps, with different slopes of tension rate increase and decrease, in comparison with isometric steady contractions named steps (ST).

2. Methods

According to the principles of the 1964 Helsinki Declaration on humans beings scientific research studies and after fully information about the aim and the experimental procedure 12 male subjects (25–33 years old with no neuromuscular diseases) volunteered to participate in the study. The investigated muscle was the first dorsal interosseus (FDI). All the recordings were carried out in a constant temperature room set at 22 °C. The experimental set-up is represented in Fig. 1. The forearm of the subject was positioned halfway between pronation and supination in a custom designed brace and fixed, as the last three digits of the hand, by straps to the rigid frame. The index finger and the thumb were at an angle of 90°. The second phalanx was connected to a

load cell (Metro, SM-50N) in order to measure the FDI tension during isometric effort in abduction. The signal was filtered (0–128 Hz) before storing. The surface EMG was detected by two silver bars (10 × 5 mm) 10 mm spaced, fixed to the muscle surface by an adhesive elastic tape (Fixomull) after cleaning the skin with ethyl alcohol and after application of a conductive gel. The inter-electrode axis was kept parallel to the muscle fibres orientation. Reference electrode was strapped at the subject wrist. The EMG was filtered (bandpass 10–500 Hz). EMG and force signal were then stored (1024 Hz) in a personal computer for off-line processing. After MVC determination (highest of three consecutive efforts lasting 3 s and with 1 min interval in between them) the subject performed:

- Two trapezoid isometric contractions: 0–50–0% and 0–100–0% MVC having 6.7% MVC/s and 13.3% MVC/s, respectively (3 min between each of them). At the end of the UGR the reached effort level was maintained for 1 s before DGR began;
- 10 Sustained 6 s long contractions (nine steps, 10–90% MVC step 10, plus 5% MVC); between each step 3 min rest were allowed.

The requested output tension (% MVC target) was provided on a PC screen together with the force from the subject for the necessary visual feedback. According to Orizio et al. (2003), for off-line processing the EMG and force signal 1 s time windows were centred every 5% MVC (range 5–45% MVC) or 10% MVC (range 10–90% MVC) during the 6.7% MVC/s and 13.3% MVC/s ramps, respectively. The chosen ranges of % MVC during UGR and DGR allowed to study EMG and force signal out of transient responses (see black lines in Fig. 3). The same 1 s time window, centred between 2.5 and 3.5 s, was used for ST series. The analysis of EMG was performed in the time and in the frequency domains by calculating the power content of the signals as root mean square (RMS) and the mean frequency (MF) as a parameter of the power spectrum density distribution obtained by the Fast Fourier Transform. From the force signal per each identified time window (see above) we calculated sample by sample the relative error (% ERR) of the subject output tension with respect to the requested target value according to the following formula: (actual output tension – target tension)/target tension × 100. The degree of unsteadiness of the mechanical output was then summarised by the parameter % ERR computed averaging the 1024 relative errors over the entire 1 s time window.

2.1. Statistics

Given that EMG-MF and EMG-RMS as well as % ERR parameters values distribution did not always pass normality test, non-parametric analysis was used. ANOVA on ranks was applied twice: first to analyse the effect of the force (% MVC) factor, within the same type of isometric contraction (ST, UGR, and DGR); second to analyse the effect of the type of contraction (ST, UGR, and DGR) factor, within the same intensity of isometric effort (same % MVC). When the main analysis indicated a significant effect of the considered factor (type of contraction or level of effort) post hoc analysis was performed using Newman–Keuls test. The statistical analysis was ran for each parameter (EMG-RMS, EMG-MF and % ERR) at 5%, 10%, 20%, 30% and 40% MVC when comparing the values from ST, UGR (6.7% MVC/s) and DGR (–6.7% MVC/s); 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40% and 45% MVC when comparing the values from UGR (6.7% MVC/s) and DGR (–6.7% MVC/s) separately for evaluation of the effort (% MVC) effect; 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80% and 90% MVC when comparing the values from ST, UGR (13.3% MVC/s) and DGR (–13.3% MVC/s). During 6.7% MVC/s ramps the influence of UGR and DGR type of effort was checked

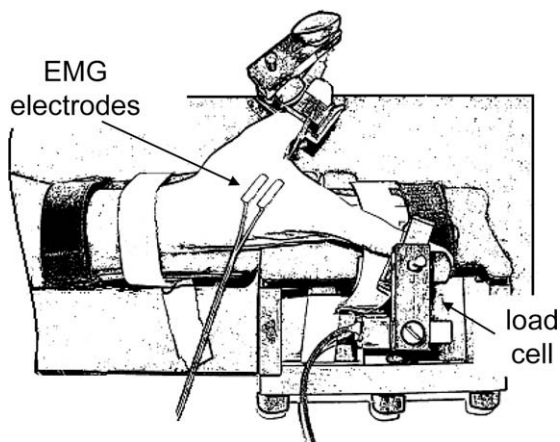


Fig. 1. Schematic representation of the isometric ergometer for detection of the tension provided during abduction in the vertical plane of the second digit due to voluntary action of the first dorsal interosseus muscle. The electrodes for surface EMG detection and the load cell for tension recording are indicated. The angle between the first and the second digit is 90°. See text for details.

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