INTRODUCTION

Previous studies have indicated that mechanomyogram (MMG) amplitude and frequency components might represent the underlying motor unit (MU) recruitment and firing rate (rate coding)(Barry and Cole, 1990; Orizio et al., 1993, 1996; Bichler, 2000). Interestingly, MMG amplitude actually decreases at higher force levels at which MUs might be firing at tetanic rates, causing a fusion-like contraction leading to diminished MMG amplitude due possibly to the reduction of lateral expansion of the muscle fibres, while its frequency increases (Moritani and Yoshitake, 1998; Yoshitake and Moritani, 1999). These data suggest that MMG analyses might offer not only MU recruitment and rate coding characteristics, but also their mechanical properties, the fusion properties of activated MUs that could not be obtained by conventional EMG analyses. In the present series of studies, we have attempted to validate this notion by performing MMG amplitude and frequency domain analyses during graded voluntary contractions as well as during controlled micro-stimulations of isolated human MUs in the triceps surae muscles.

METHODS

We employed microphone sensors (10 mm diameter, mass 5g, bandwidth 5-2000Hz) for our entire MMG recording. MMG and EMG signals were recorded simultaneously from the relatively fast medial gastrocnemius (MG) and slow soleus (SOL) during voluntary and electrically induced contractions.

Fourteen isolated MUs were studied in the medial gastrocnemius (MG) muscle of 7 healthy male subjects. Two identical microphone sensors (10 mm diameter, mass 5g, bandwidth 3-2000 Hz) for MMG recording were fixed to the centre of the belly of MG at 0.5 cm apart where two fine bipolar wire electrodes were inserted for different depth so as to stimulate isolated MUs. Single twitch and repetitive micro-stimulations were performed at 5, 10, 15, 20, 30, and 50 Hz, while simultaneously recording the evoked mass action potentials (M-wave) remained constant. Effects of mixed stimulations were also studied by stimulating two MUs at 5-10, 10-20, 8-12, and 12-24 Hz, respectively. In addition, isolated MU fatigue trials were performed at 12 Hz for a period of 2-min in order to determine the relationship between muscle contractile slowing and the corresponding MMG amplitude and frequency components.

Effects of muscle temperature upon contractile properties and the corresponding MMG changes were also examined during experimentally-induced hypothermia. For the practical application, we also investigated the aetiology of lower-back muscle fatigue by means of simultaneous analyses of EMG, MMG, and near-infrared spectroscopy (NIRS) in an attempt to shed some light on the electro-physiological, mechanical, and metabolic characteristics of low back muscle fatigue (Yoshitake et al., 2001).

RESULTS AND DISCUSSION

Results indicated that the MMG amplitude of medial gastrocnemius (MG) increased as a function of force whereas these values for SOL increased up to 60% MVC, but then decreased at 80% MVC due to possible MU fusion resulting in smaller muscle dimensional changes. Similarly, a significant reduction in the muscle contractile properties (Peak force, maximal rate of force development and relaxation, contraction and half-relaxation times, etc.) caused by the experimental hypothermia also resulted in significant reduction in MMG amplitude with subsequent fusion at lower stimulation frequency. Different stimulation frequency trials indicated that there were highly significant and progressive reductions in the force fluctuations from 5 Hz to 50 Hz that were almost mirrored by the similar and significant reductions in the MMG amplitudes. Mixed stimulations to different MUs clearly demonstrated that both MMG and force recordings showed two distinguished peak frequencies that were delivered to the underlying MUs.

Lastly, our MU fatigue study with prolonged stimulation at 12 Hz demonstrated that MMG amplitude decreased progressively as contractile slowing occurred as a function of time. Low back muscle fatigue study also indicated that there were significant initial increases in MMG amplitude that were followed by progressive decreases at the end of fatiguing contractions. Simultaneous recordings of EMG, MMG, and NIRS demonstrated that restriction of blood flow due to the high intramuscular mechanical pressure was one of the most important factors to evoke the muscle fatigue particularly in low back muscle.

In conclusion, our data strongly suggest that MMG analyses could be employed to study MU fusion properties together with recruitment and rate coding characteristics during various experimental conditions.

REFERENCES


ACKNOWLEDGEMENTS

This work was supported in part by a grant-in-aid for Scientific Research (B) no. 115300231 from the Japan Ministry of Education, Science, Sports, and Culture.