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Effects of Voluntary Breathing on Force Responses to Electrical Stimulation (ES) of Finger Extensors : A Pilot Study

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Effects of voluntary breathing on force responses to electrical stimulation (ES) of finger extensors: a pilot study

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Abstract

Voluntary breathing can influence motor functions of non-respiratory skeletal muscles, e.g., finger muscles. The influence was proposed to be mediated by the ventilation-associated enhancement on corticospinal excitability of the finger muscles, possibly including spinal mechanisms. Force responses to electrical stimulation include spinal mechanisms. The purpose was to investigate the potential spinal mechanism mediating the voluntary breathing effects on responses of finger extension forces to electrical stimulation. A single-pulse electrical stimulation of the same intensity was delivered to the extensor digitorum communis (EDC) during voluntary breathing (forced inspiration, IN and force expiration, OUT) and normal breathing (Norm) across various submaximal levels (10 ~30%) of isometric finger extension. Among the tested 3 subjects, differences of background finger extension forces were 2~3% at each force level. The evoked force increment was greater during IN and OUT than during Norm consistently at all tested force levels. However, the increment seemed not to be different between IN and OUT. Latency of the ES-evoked response was in the range from 52ms to 68ms. These pilot results demonstrated that voluntary breathing modulated finger extension force responses to electrical stimulation, most likely mediated by spinal mechanisms.

1 Introduction

Voluntary breathing has been shown to impose a great impact on motor functions of non-respiratory skeletal muscles [3, 4]. For example, peak force increased significantly from forced inspiration to forced expiration (about 10%). The ventilation-associated effect was proposed to be mediated by a mechanism [3] that enhanced activation in cortical respiratory centers, associated with initiation of forced respiration, influences corticospinal excitability of the non-respiratory finger muscles, possibly including spinal mechanisms. Force responses to neuromuscular electrical stimulation (ES) include spinal mechanisms [5].

The purpose of this experiment was to investigate the potential spinal mechanism mediating modulation of the ES-evoked force response during voluntary breathing. It was hypothesized that, when the same intensity of ES is delivered at the same background force of the finger extensors, the ES-evoked force increment is greater during forced inspiration and expiration than during normal breathing.

2 Methods

Three young and healthy male subjects participated in the experiment after giving informed consent.

A customized finger force device (Fig 1) was used. The forearm was stabilized in the neutral position by Velcro straps at the proximal and distal sites. The palm was stabilized by Velcro straps with the wrist joint at about 20º of extension. The metacarpophalangeal (MCP) joints were stabilized at approximately 20º of flexion with the shaft of the proximal phalanges against Futek (model LSB200) sensors. The sensors have a range of -25lb to 25lb (about -110 N to +110N). The distal parts of the fingers were instructed to be naturally curved during isometric finger extension against force sensors. Similarly, the highest value of three maximal voluntary contraction (MVC) attempts of the middle finger was selected to create target force levels.

The neuromuscular electrical stimulation was a single pulse (pulse duration, 0.1ms). The pulse was randomly triggered from a digital stimulator by voluntary breathing. Two carbonized-rubber electrodes were attached to the skin overlying the muscle belly of extensor digitorum communis (EDC) muscle. The cathode (3cm×5cm) was placed over the muscle

belly just distal to the origin of EDC. The anode (1.5cm×3cm) was attached to a site distal to the cathode. The site for the anode was searched for isolated finger force responses. According to our pilot study, isolated force responses from the middle finger were most consistent and easiest to evoke while the response from the wrist joint was able to be kept minimal. The maximal output from the stimulator was 150V. The maximal output, however, was never used due to the evoked pain. The intensity of electrical stimulation was selected based on the following criteria: 1) isolated finger extension responses are detected with minimal involvement of wrist joint responses; 2) maximal tolerance of the subject to the evoked pain. The absolute magnitude of stimulation intensity may vary across subjects. However, the intensity was kept the same across different conditions for the same subject, because the purpose was to examine the effect of voluntary breathing on evoked responses within subjects, i.e., within-subject comparisons.

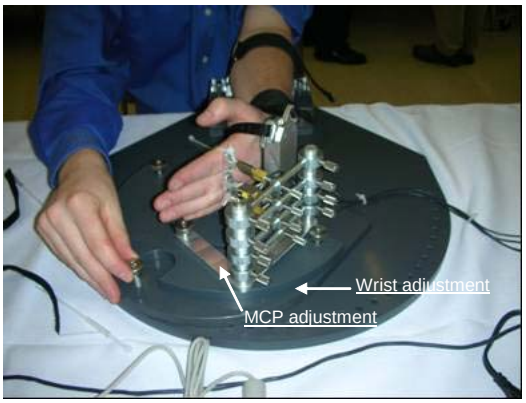


Fig 1 Finger force device. The device allows measuring individual finger forces at the shift of proximal phalange with adjustable wrist and MCP joint angles. The device also allows measuring both flexion and extension forces for both left and right hands.

During testing, subjects were seated on an adjustable chair and breathed through a facemask connected to a pneumotach system (Series 1110A, Hans Rudolph, Inc, Kansas City, MO) to monitor breathing. The middle finger MVC was first determined from three MVC attempts during normal breathing. Finger force targets were then created and displayed on the computer screen at 10%, 20%, 30%MVC, respectively. Subjects were instructed to generate a middle finger extension force matching the displayed target line as accurate as possible during a 10-s trial. No specific instructions were given to other fingers.

The electrical stimulation was delivered to the EDC directly during the following three breathing conditions: 1) Norm, 2) IN, and 3) OUT. During Norm, ES was randomly triggered between 4 s and 7 s with intervals of 1 ms. During IN, ES was triggered when forced inspiration reaches 40% of maximal inhaling airflow rate within the 4 – 7s window. The same method was applied to the OUT condition. About 10 trials were allowed as a familiarization session. Subjects were explicitly instructed to maintain a constant force production before the ES delivery and to relax after the delivery. Ten trials of each condition were tested. Conditions were randomized.

Two main dependent variables were measured: the background force prior to ES (F_{BG}) and the ES-induced force increment (F_{INC}). F_{BG} was defined as the mean averaged over a 100-ms window prior to the ES delivery. F_{INC} was the difference between the peak response and F_{BG}. Although evoked responses may be observed involving the wrist joint, and other fingers, only the middle finger force data were used to examine the main effects of voluntary breathing on the voluntary contraction. F_{INC} was averaged across 10 trials for each condition. The latency of the increment was also measured. The latency was defined as the interval between the moment of ES delivery and the moment of peak force response.

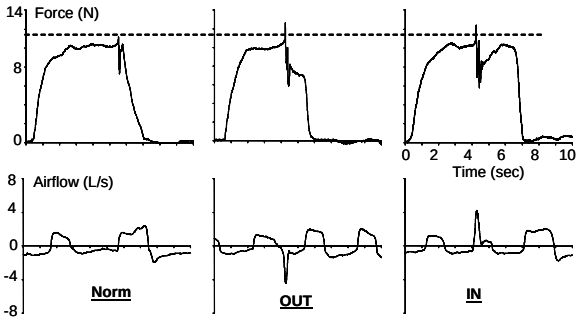
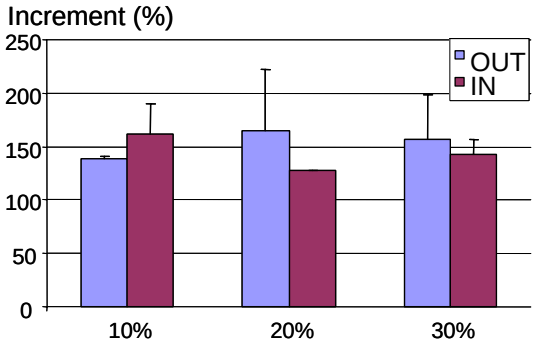


Fig 2 Typical force responses to ES over the finger extensors during isometric finger extension of the middle finger at 30% MVC. As compared to the ES induced force increment during Norm ($F_{INC,}$ indicated by the horizontal dotted line), the F_{INC} increased during OUT and IN. Note that the background force was almost the same across breathing. Airflow: positive indicates inspiration; negative indicates expiration.

3 Results

Differences in background forces across breathing conditions were about 2~3% at each

force level. The evoked force increment was greater during IN and OUT than during Norm consistently at all tested force levels (Fig 2). However, the increment seemed not to be different between IN and OUT (Fig 3). Latency



was in the range from 52ms to 68ms.

Fig 3 Averaged (N=3) force increment during voluntary finger extension. The increment was normalized to that measured during normal breathing. The normalized increment increased considerably and consistently across all tested force levels from 10 to 30%MVC of the middle finger extension. The overall normalized increment was 153.2% during OUT, 143.2% during IN.

4 Discussion and Conclusions

In this pilot study, when ES of the same intensity was delivered to the EDC at the same level of finger extension, the evoked force increment was greater during IN and OUT than during Norm consistently at all tested force levels (10 ~ 30% MVC). However, the increment seemed not to be different between IN and OUT. These results clearly demonstrated that the ES-induced force increment was modulated by voluntary breathing.

Latency was in the range from 52ms to 68ms. The range was also consistent with the previous report by Yue et al [5]. The monosynaptic pathway (e.g. tendon reflex) for the finger flexors is about 24 ms [2]. It takes about 17ms for muscle force to rise as a consequence of electrical stimulation [5]. As such, the observed modulations of the evoked increment during voluntary breathing could be attributed to spinal mechanisms [5]. Furthermore, these results were consistent with earlier reports from animal studies [1] that spinal motor neurons could integrate different sources of inputs, including afferent inputs and descending inputs, into neuronal network, resulting in modulations of motor functions based on these inputs.

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Acknowledgements

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