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The effect of contraction intensity on force fluctuations and motor unit entrainment in individuals with essential tremor

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ABSTRACT

Objectives: Quantify the effect of increasing contraction intensity on the amplitude of force fluctuations and neuromuscular and force tremor spectral power.
Methods: Twenty-one subjects with essential tremor (ET) and 22 healthy controls applied isometric wrist extension contractions. Various sub-maximal contraction intensities were evaluated (5%-, 10%-, 20%- and 30%-MVC). Force fluctuations and wrist extensor neuromuscular activity were recorded using a load cell and electromyography (EMG).
Results: Higher contraction intensities were associated with larger amplitude force fluctuations and greater neuromuscular activation. However, spectral power associated with tremor peaks remained relatively constant (EMG) or decreased (force) with increasing contraction intensity.
Conclusions: Motor unit entrainment associated with centrally generated oscillatory inputs does not increase with greater levels of muscle activation.
Significance: Rather than influencing a constant proportion of active motor units, abnormal oscillatory drive influences a relative constant number of total motor units. When combined with the findings from our previous study on postural tremor, the present results provide preliminary evidence that abnormal stretch reflex activity may contribute to this motor unit entrainment.
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1. Introduction

Recently we have shown that rhythmical motor unit entrainment does not significantly increase when individuals with ET support light to moderate loads despite an increase in overall neuromuscular activity (Héroux et al., 2009). With postural tremor, however, abnormal descending oscillatory activity may interact (synergistically or competitively) with short- and long-latency stretch reflexes caused by oscillatory motion (Elble et al., 1987; Matthews, 1993; Elble, 1996). Thus, we sought to investigate the influence of contraction intensity on the strength of motor unit entrainment in subjects with ET during closed-kinetic chain isometric contractions since the influence of stretch reflexes during such contractions is minimized (Burne et al., 1984; Doemges and Rack, 1992).

Previously, Gillies (1994) noted an increase in force fluctuation amplitude with increasing contraction intensity in a report involving an unspecified number of ET subjects. Based on visual inspection, the author states that the tremor spectral peak represented a constant proportion of spectral power across a wide range of contraction intensities (5–95% maximal voluntary contraction (MVC)) and concludes that the central oscillator in ET affects a constant proportion of the central drive to the motor neuron pool. More recently, Bilodeau et al. (2000) reported an increase in force fluctuation amplitude with increasing contraction intensity in subjects with ET. Of particular interest was the anecdotal report that tremor spectral peak amplitude appeared to increase at the higher contraction intensity (2.5%- versus 20%-MVC), indicating that force tremor scaled with contraction intensity. Corroborating these findings, Burne et al. (2004) noted a linear increase in electromyography (EMG) tremor spectral peak amplitude when subjects with ET generated various low level isometric contractions (<5%-MVC). It remains unclear, however, whether the increase in tremor spectral power – both in force and EMG signals – increases proportionally to the overall level of muscle activation or whether, similar to what was previously reported for postural tremor, motor unit entrainment is proportionally greater at lower contraction intensities.

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The purpose of this study was to quantify the effect of increasing contraction intensity on the amplitude of neuromuscular and force tremor spectral power in order to determine whether or not the central oscillatory drive in ET affects a constant proportion of the motor neuron pool as suggested by Gillies (1994). In contrast to our previous study, closed-kinetic chain isometric contractions were used to minimize the influence of stretch reflex to the ongoing neuromuscular activity.

2. Methods

2.1. Subjects

Twenty-one subjects with ET and 22 healthy control subjects of similar age participated. Subjects with ET were divided into two groups based on the strength and consistency of motor unit entrainment during isometric force production (see Section 2.5.2 for details; Héroux et al., 2009); two subjects with mild tremor from the previous study had highly variable and often absent motor unit entrainment at all target intensities and their data were not included. Subjects in the ET groups: (1) met the diagnosis criteria of the Consensus Statement of the Movement Disorder Society on Tremor (Deuschl et al., 1998), (2) did not present with factors associated with misdiagnosed ET or other red flag items (Elble, 2000; Jain et al., 2006) and (3) had spectral plots of hand postural tremor and forearm EMG recorded under various loading conditions that were consistent with ET (see Héroux et al. (2009) for details). All subjects provided informed consent to the protocol, which was approved by the local Research Ethics Board.

2.2. Apparatus

The subject was seated in front of a computer monitor. The forearm of the side being tested was in full pronation and supported on a height-adjustable table with the wrist in neutral flexion/extension and neutral radial/ulnar deviation. Two straps secured the forearm to the table and a piece of opaque fabric prevented the subject from seeing their forearm and hand during testing. Voluntary isometric wrist extension contractions were made against a support device connected to a load cell (MLP100, Transducer Techniques) secured to the table.

During MVC testing, the load cell signal was conditioned (Dataforth DSCA43–10 strain gage input conditioner), filtered using an eighth order analogue Butterworth filter (Max740, Maxim) and sampled at 1024 Hz by a 16-bit analog-to-digital converter (National Instrument PCI-MIO-16XE-10) controlled by a Pentium Xeon 2.66 GHz personal computer. During %-MVC trials, the load cell signal was also amplified with an amplifier gain of 8 (Burster Model 9243) prior to being sampled. For MVC testing the smallest detectable change in force was 0.231 N (range: 0–448 N), whereas it was 0.028 N (range: 0–56 N) for %-MVC testing.

The computer monitor (21 in. Dell M992, 60 Hz refresh rate, set to 1024×768 pixels) was positioned 50 cm from the subject; the top of the viewing area was in line with the eyes. During %-MVC testing the subject viewed a vertically centered horizontal line that spanned the width of the viewing area and corresponded to the target force being assessed. A second line corresponding to the force exerted on the load cell scrolled left to right during the trial; the total width of the viewing area corresponded to 12 s. The vertical axis was scaled to ±6 N of the target force for all %-MVC testing resulting in a visual gain of 50 pixels/N. The visual angle of feedback, which is dependent on eye–monitor distance and visual gain, has been shown to influence the amplitude and structure of force fluctuations (Vaillancourt et al., 2006). Pilot testing on healthy subjects revealed that the steadiest trial (target intensity 5%-MVC) resulted in a visual angle of 1.15°, which ensured that the potential influence of visual angle on force fluctuations was negligible (see Vaillancourt et al. (2006) for details).

Surface EMG was used to measure the neuromuscular activity of the extensor carpi radialis brevis. Skin preparation, electrode placement and the EMG system used were the same as previously described (see Héroux et al. (2009) for details). The EMG signal was digitized using the previously mentioned 16-bit analog-to-digital converter; all EMG data were sampled at 1024 Hz. Load cell and EMG data were collected using custom-built Labview 8 software (National Instruments) and saved to the hard disk of the personal computer for subsequent analysis.

2.3. Procedure

In subjects with ET, the hand reported to have the most severe tremor was measured. In the case of symmetrical tremor, the dominant hand was tested. The side tested in healthy controls was selected in order to obtain approximately the same dominant/non-dominant ratio between ET and control groups.

The MVC of the wrist extensors was first determined. Following a brief warm-up consisting of 3–4 sub-maximal contractions, the subject performed three successive maximal static contractions lasting 5 s with a 120 s rest period between contractions. Next, the subject was asked to produce and hold a series of constant force contractions at four sub-maximal intensities (5%, 10%, 20% and 30% of MVC). The subject was instructed to extend the wrist against the support device and superimpose the force line overtop of the target line on the monitor. After the initial rise in force and stabilization period, the subject held this level of force production with visual feedback for 8 s. Two blocked trials were recorded at each target intensity; the order of testing of the four target intensities was selected randomly. There was a 60 s rest period between trials of a given block and a minimum of 120 s rest between each block.

2.4. Data processing

Prior to performing all data analyses, load cell and EMG data were conditioned by the following methods. The EMG data were digitally rectified and the offset value was removed. Next, the EMG and load cell data were digitally filtered using a dual-pass fourth order Butterworth filter with a low-pass cut-off frequency of 40 Hz. Furthermore, the 8 s window of force data from each trial was linearly detrended. All data processing and subsequent time and frequency analyses were performed using software written in Matlab 7 (The MathWorks, Inc.).

2.4.1. Amplitude of force fluctuations and EMG activity

The maximum force value produced across all three trials was selected as the MVC value. Overall force fluctuation amplitude during %-MVC trials was determined by calculating the standard deviation of the force time series. This is a global measure that does not distinguish between force fluctuations associated with pathological tremor (4–12 Hz) from those related to visuomotor corrections (0–3 Hz) and normal physiological force variability (8–12 Hz) (Elble, 1996; Jones et al., 2002; Slifkin et al., 2000). For the EMG signal, the mean level of neuromuscular activity for each trial was computed. The mean of both trials from a given target force was computed for all measures and used for statistical analysis.

2.4.2. Spectral measures of isometric force tremor and neuromuscular activity

Force and EMG auto-spectra were calculated for each target intensity and visual condition using the method of disjoint sections (Halliday et al., 1995). The spectra were estimated by averaging the

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