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NEUROLOGY AND PRECLINICAL NEUROLOGICAL STUDIES - SHORT COMMUNICATION

Coherence of coactivation and acceleration in task-specific primary bowing tremor

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Abstract Coherences between coactivation of wrist antagonist muscles and movement fluctuation were assessed in four violinists with a task-specific tremor and four age-matched healthy violinists using electromyography and accelerometer. We found coherence between individual muscular activation and tremor only in patients at a frequency range of 3–8 Hz. The finding corroborates the notion that primary bowing tremor emerges mainly due to central neurogenic contributions via motor-unit synchronization. Furthermore, the coherence between the muscular coactivation and tremor suggests a relation of the tremor to dystonia.

Keywords Coherence · Tremor · EMG · Task-specificity · Dystonia · Essential tremor

Introduction

Task-specific tremors (TST) occur predominantly during a certain task (Deuschl et al. 1998) with the most common form being primary writing tremor (PWT) (Deuschl et al. 1998). TST of the upper limb may also occur in string-instrument players as primary bowing tremor (PBT) (Lee and Altenmüller 2012; Lederman 2012), a severely impairing condition, often threatening the professional career. However, little is known about its pathophysiology. It is an ongoing debate, whether TSTs are a manifestation of focal dystonia (FD) or a sub-entity of essential tremor (ET) (Deuschl et al. 1998; Rosenbaum and Jankovic 1988). One of the main pathognomonic features of dystonia is a coactivation of antagonist muscles (Cohen and Hallett 1988; Farmer et al. 1998; Torres-Russotto and Perlmutter 2008). We recently identified electromyography (EMG) activity of wrist flexor and extensor muscles in the frequency range of 3–8 Hz in PBT (Lee et al. 2013). One drawback of that study, however, was that only EMG was assessed. Thus, a causal relationship between EMG activity, especially coactivation, and oscillatory movement measured by an accelerometer (tremor) has not been evaluated yet. What is new in this paper is the quantitative assessment of the relationship of muscular activity with movement acceleration gained by accelerometry. For this, we calculated the coherence between tremor-related movement fluctuation (i.e. acceleration) and wrist flexor and extensor activity as well as between tremor and coactivation of these muscles. The coherence calculation was motivated since it provides frequency domain information on the neuromuscular contribution to movement fluctuation, i.e. tremor (McAuley et al. 1997; Halliday et al. 1999).

We hypothesized that a coherence exists not only between tremor and EMG activity of wrist flexor and extensor muscles but also between tremor and their coactivation. We predicted coherence in the frequency range of 3–8 Hz. To assess the specificity of a coherence to the patients with TST, age- and gender-matched healthy violinists were recruited as a control group.

Methods

The study was approved by the local ethics committee. Informed consent was obtained from the participants. Four

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professional violinists (aged 48–62, median 53.5) with PBT of the wrist and age-matched healthy controls (aged 44–68, median 53.5, Wilcoxon, $p = 1$) were investigated (group). Two conditions were measured: a G-major scale (GM) and open strings (OS) were played with a metronome at 40 bpm. Since patients had a wrist flexion–extension tremor, surface EMG was recorded from wrist flexor and extensor muscles (muscle-groups). Accelerometer data (biovision Wehrheim, Germany) was recorded from the metacarpo-phalangeal joint of the index finger (sampling rate 500 Hz). We chose this site in order to obtain tremor closely to the bow, where it most affected the playing. However, a placement of the accelerometer on the bow would have interfered with playing. EMG data were band-pass filtered (2–450 Hz) to remove artifacts and rectified. For smoothing the signal a low-pass filter (13 Hz) was then applied. Next the data were normalized and a fast Fourier transformation (FFT) was applied. Finally the average and standard deviation of tremor power for all patients was calculated. Coactivation was computed with the following equation by computing the overlap of the waveforms of the wrist antagonist muscles (Furuya et al. 2012):

$$\mathrm{CI} = \left(\int_{t1}^{t2} \mathrm{EMG}_{\mathrm{agon}}(t)\mathrm{d}t + \int_{t2}^{t3} \mathrm{EMG}_{\mathrm{ant}}(t)\mathrm{d}t \right) \Big/ \Delta T$$

where the period from t_1 to t_2 denotes the time when the agonist EMG activity is less than the antagonist EMG and vice versa for the period from t_2 to t_3. ΔT is an entire movement period for performing the present task. We then calculated the coherence between the accelerometer data and the EMG signal of each single muscle or their coactivation, respectively, using mscohere function in Matlab, specifying 2,048-points length of Hanning window. For statistical analysis, we subdivided the frequency into three ranges (1–3, 3–8 and 8–12 Hz) (Bain 2011). Next a three-way ANOVA with the coactivation as the dependent variable and group (patient, control), frequency band (see above) and condition (open strings, G-major scale) as independent variables was conducted. Similarly, a three-way ANOVA was conducted with the flexor-EMG signal as dependent variable and the extensor EMG signal as dependent variable. Finally a two-way ANOVA was applied for the peak frequency as dependent variable and muscle group (flexor/extensor) and condition (open string/G-major scale) as independent variables.

Results

We found a coherence between EMG activity of the individual muscles and tremor as well as a coherence between their coactivation and tremor particularly in the frequency range 3–8 Hz only for the patients (Fig. 1).

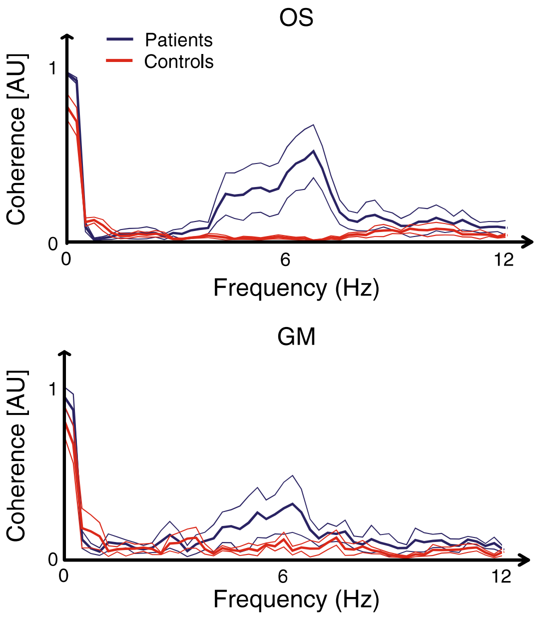

Fig. 1 Coherence between coactivation and tremor for patients (*blue*) and controls (*red*) at the wrist antagonist muscles. A clear coherence around 6.4 Hz is visible only in the patients for both conditions. *Thin lines* show the standard deviation

There was no main effect for muscle group or condition on the peak frequency (two-way ANOVA). Three-way ANOVA for the extensor revealed a main effect of group ($p = 0.027$) and frequency-band ($p = 0.011$) but not condition ($p = 0.07$). Post-hoc analysis showed a significant difference between patients and controls only in the 8–12 Hz frequency range ($p < 0.05$). Within the patients, difference was significant between the 3–8 Hz frequency range and each of the 1–3 and 8–12 Hz frequency ranges, respectively. Three-way ANOVA for the flexor revealed a main effect for group ($p = 0.044$) and frequency band ($p = 0.048$) but not condition ($p = 0.66$). Post-hoc analysis showed a significant difference between patients and controls only in the 3–8 Hz frequency range. Within the patients, a difference was significant between the 8–12 Hz frequency range and the 1–3 Hz frequency range. Three-way ANOVA for coactivation showed a main-effect of group ($p < 0.001$) and frequency band ($p << 0.001$) but not condition ($p = 0.3$). Post-hoc analysis showed a significant difference between patients and controls only in the 3–8 Hz frequency range ($p < 0.05$). Within the patients, a difference was significant between the 3–8 Hz frequency range and the 1–3 and 8–12 Hz frequency ranges, respectively (Fig. 2). The results did not differ between the conditions.

Discussion

We are aware of some limitations to our study such as system proneness to detection errors, e.g., surface EMG or accelerometry or statistical errors by applying wave

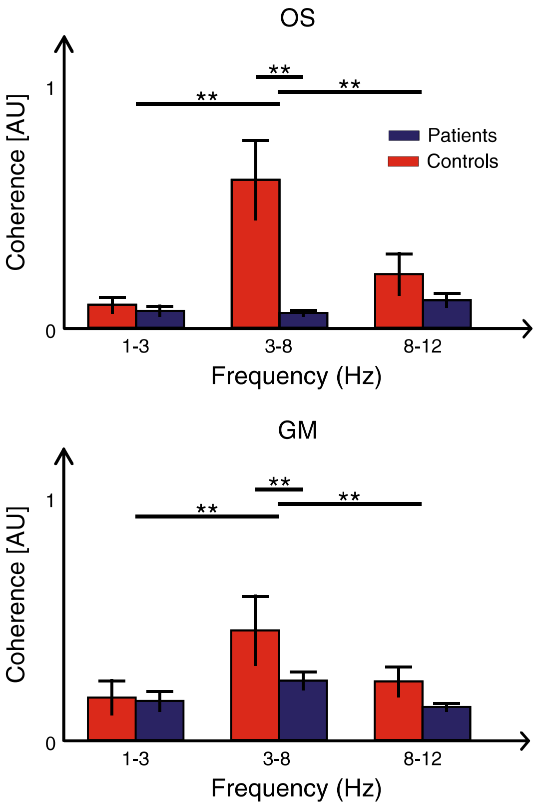

Fig. 2 Mean coherence and standard error at the three frequency-bands. Group difference is significant only in the frequency range of 3–8 Hz for both conditions. *OS* Open string, *GM* G-major scale. The *stars* show significant differences

analysis or coherence analysis. Another limitation is the small sample size; however, due to the rareness of PBT even among musicians, it is the biggest sample quantified so far.

In confirmation with our hypothesis we could show a direct relationship not only between EMG activity of wrist flexor and extensor muscles and tremor as would be expected, but also, importantly, a direct relationship became apparent also between coactivation and tremor in the frequency range 3–8 Hz. In the healthy controls no tremor signal and thus no coherence was found.

Coherence between EMG activity and tremor provides insights into central nervous contribution to tremor and corroborates the notion that PBT emerges most likely due to central neurogenic contribution via motor-unit-synchronization, which is hardly influenced by mechanical factors (McAuley et al. 1997; Halliday et al. 1999). This notion is corroborated by the fact that no coherence was found between muscular activity and the frequency of the mechanical reflex properties of the wrist of 8–12 Hz (Elble 1996). Although minor contributions of mechanical reflex properties or physiological tremor cannot be ruled out, they apparently play a minor role. We are aware that a coherence of coactivation between two limbs, e.g., between the left and the right arm, would strengthen this suggestion. One possibility would have been to make the violinists play inversely, with the bow in the left and the violin in the right hand. However, it is known that exerting an untrained task is associated with an increased coactivation of antagonist muscles that decreases with training (Osu et al. 2002). In musicians we found that less skilled musicians have an increased coactivation of antagonist muscles that decreases with practice (Furuya and Kinoshita 2008). Given the fact that professional musicians have practiced more than 10,000 h in the first 10 years of playing the instrument alone (Ericsson et al. 1993), playing the violin inversely can be regarded as an untrained task even for professional violinists. It is therefore likely that this would induce an increased coactivation thereby confounding the measurement. For the same reason, it is difficult to assess non-musicians with, e.g., essential tremor, since again a higher coactivation of antagonist muscles would be expected due to the complex task. Moreover, PBT is a unilateral tremor and thus none of our patients had any tremor in the contralateral left hand.

The confirmation of our hypothesis of a relation between coactivation and tremor is in itself an interesting finding, adding to the pathophysiological understanding of TSTs. But it is also important, because it may contribute to the question, whether TST are related to FD or ET (Deuschl et al. 1998; Rosenbaum and Jankovic 1988). With regard to phenomenology, the task-specificity of PWT and writer's cramp or PBT and musician's dystonia may be indicative for a relation between TST and FD. However, since coactivation of antagonist muscles is one of the pathognomonic features in dystonia (Cohen and Hallett 1988; Farmer et al. 1998; Torres-Russotto and Perlmutter 2008), a direct relationship between coactivation and tremor further suggests the hypothesis that TST is related to dystonia.

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