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Dystonic neck muscles show a shift in relative autospectral power during isometric contractions

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HIGHLIGHTS

- Dystonic muscles displayed increased 3–10 Hz power with reduced 10–30 Hz power.
- Similar shifts were detected in head forces and moments in cervical dystonia patients.
- We associate these shifts with prokinetic sensorimotor control.

ABSTRACT

Objective: To identify effects of a deviant motor drive in the autospectral power of dystonic muscles during voluntary contraction in cervical dystonia patients.
Methods: Submaximal (20%) isometric head-neck tasks were performed with the head fixed, measuring surface EMG of the sternocleidomastoid, splenius capitis and semispinalis capitis in CD patients and controls. Autospectral power of muscle activity, and head forces was analyzed using cumulative distribution functions (CDF). A downward shift between the theta/low alpha-band (3–10 Hz) and the high alpha/beta-band (10–30 Hz) was detected using the CDF_{10}, defined as the cumulative power from 3 to 10 Hz relative to power from 3 to 30 Hz.
Results: CDF_{10} was increased in dystonic muscles compared to controls and patient muscles unaffected by dystonia, due to a 3–10 Hz power increase and a 10–30 Hz decrease. CDF_{10} also increased in patient head forces.
Conclusions: Submaximal isometric contractions with the head fixed provided a well-defined test condition minimizing effects of reflexive feedback and tremor. We associate shifts in autospectral power with prokinetic sensorimotor control.
Significance: Analysis of autospectral power in isometric tasks with the head fixed is a promising approach in research and diagnostics of cervical dystonia.

1. Introduction

Idiopathic cervical dystonia (CD) is a neurological movement disorder characterized by involuntary neck muscle contractions (Fahn, 1988). The pathophysiology of CD remains unclear, although functional and morphometric changes have been found in several brain areas, such as the cerebral cortex (Draganski et al., 2003; Egger et al., 2007; Obermann et al., 2007; de Vries et al., 2012), superior colliculus (Holmes et al., 2012), thalamus (Krauss et al., 1999; Chang et al., 2002; Butterworth et al., 2003; Kupsch et al., 2006; Vidailhet et al., 2007), and cerebellum (LeDoux and Brady, 2003; Neychev et al., 2008; Sadnicka et al., 2012; Prudente et al., 2013). Current evidence points towards differences in the neuronal circuitry of multiple areas in the brain (Berardelli et al., 1998; Lehéricy et al., 2013). In particular, power in local field potentials (LFP) of the Globus Pallidus internus (GPi) shows an increase around 4–10 Hz and a reduction around 11–30 Hz (beta-band) in generalized and cervical dystonia patients (Silberstein et al.,

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2003). Such beta-band brain rhythms are thought to contribute to sensorimotor control opposing the execution of movement (Pfurtscheller et al., 1996; Engel and Fries, 2010), i.e. contribute antikinetically, and frequencies above 60 Hz (gamma-band) are considered prokinetic (Engel and Fries, 2010). It is hypothesized that aberrance in these rhythms may relate to the hyperkinesia in CD patients (Weinberger et al., 2012). Indeed, excessive 3–10 Hz (Chen et al., 2006; Sharott et al., 2008) and reduced 8–20 Hz (Liu et al., 2008) pallidal activity may correlate with dystonic tremor (Deuschl et al., 1998).

Muscle (electromyography) frequency spectra have been used to identify specific movement disorders. For example, in patients with writer's cramp, increased 11–12 Hz intermuscular coherence between limb muscles has been found in comparison to controls mimicking similar muscle activation patterns. This indicates aberrance in synchronization of presynaptic inputs (Farmer et al., 1998). In limb dystonia, autospectral EMG of muscles with clinical signs of dystonia exhibits less relative power above 70 Hz than healthy subjects (Go et al., 2014). Symptomatic limb dystonia patients carrying the DYT1 gene show a 4–7 Hz peak in the autospectrum of affected limb muscles, which is absent in asymptomatic carriers, patients with fixed dystonia, and controls (Grosse et al., 2004). In CD, differences between autospectral EMG of dystonic and healthy muscles have been found, where peaks around 10–12 Hz were absent in dystonic splenius capitis (SPL) muscles (Tijssen et al., 2000, 2002). Similar experiments with a larger patient and control group only partially confirmed these results (Nijmeijer et al., 2014). Within patients, autospectral peaks between 8 and 14 Hz were absent in 7 out of 9 affected SPL muscles but also in 3 out of 10 unaffected SPL muscles, providing a limited discriminative power. These observations, however, were made in seated subjects with their head free while applying forces to a handheld device. Considering that 2 out of 10 patients demonstrated an obvious tremor (Nijmeijer et al., 2014), reflexive feedback in reaction to dystonic and/or tremulous movement during these head free conditions may have caused healthy muscle activity providing misleading results.

The aim of the present study was to determine whether differences in the autospectral EMG could be observed between muscles clinically diagnosed to be dystonic and healthy muscles when head movement was eliminated through isometric fixation of the head and torso. Head fixation and head force feedback provided a standardized task with precise contraction instructions in direction and amplitude. It also minimized reflex contributions to muscle activity since reflexive stabilization of the head and neck was not needed, thus allowing observed differences between patients and controls to be attributed to a central rather than peripheral origin. We hypothesized that the dystonic muscles would show a similar, but more consistent, shift in power of the EMG spectra during isometric contractions as compared to head free conditions. More specifically, we predicted there would be a relative drop in the high alpha/beta-band (10–30 Hz) (Tijssen et al., 2000, 2002) and an increase in theta/low alpha-band (3–10 Hz) (Deuschl et al., 1998; Liu et al., 2008). In addition, by fixating subjects to an overhead load cell, we extended our analysis to examine changes in the net motor output (forces and moments) during neck muscle contraction tasks. We hypothesized that a 3–10 Hz increase and a 10–30 Hz decrease would also be visible in the measured forces and moments of CD patients during isometric muscle contractions.

2. Materials and methods

This paper presents partial results of a series of three experiments performed on the same group of CD patients. 1) Head free tasks at the Amsterdam Medical Center with EMG spectral analysis in isometric tasks (see introduction) and intermuscular coherence analysis (Nijmeijer et al., 2014). 2) Isometric tasks with the head fixed at Delft University of Technology, where performance and muscle coordination were reported in de Bruijn et al. (2015) and where the current paper presents spectral analysis of muscle activity and head forces and moments. 3) Dynamic stabilization tasks on a motion platform at Delft University of Technology (Forbes et al., 2017).

2.1. Experimental

Experiments were carried out with ethical approval from the Delft University of Technology and the Amsterdam Medical Center, in accordance with the Declaration of Helsinki. All participants gave written informed consent.

2.1.1. Subjects

Ten CD patients (5 males, age 56 ± 11 years) and ten age matched controls (4 males, age 55 ± 14 years) participated in the experiments at the Delft University of Technology. The severity of the disorder for each patient was quantified using the TSUI (Tsui et al., 1985) and TWSTR (Consky and Lang, 1994) scales. All patients were under the treatment of botulinum toxin (BoNT) and to minimize effects of treatment the experiments were performed at least three months after the last BoNT injection. In the analyses, muscles that were identified during clinical assessment for the purposes of BoNT treatment were considered to be dystonic. This allowed for grouped comparisons between dystonic and unaffected patient muscles. Dystonic muscles varied per patient and are listed in Table 1.

2.1.2. Isometric task

Subjects were seated and wore a tightly fitted cushioned helmet that was fixed in an isometric device (de Bruijn et al., 2015). Visual feedback of the generated force magnitude and direction (in force tasks) and twist moment magnitude (in moment tasks) was presented through a custom made interface (de Bruijn et al., 2015) to improve the reliability of submaximal contraction tasks (Burnett et al., 2007).

Head forces and moments were measured by an overhead six axis load cell (MC3-6-500, AMTI Inc., Watertown, USA). Force and moment signals were passed through an analogue low-pass filter (2nd order, critically damped at 1024 Hz) and sampled at 2000 Hz. Surface EMG was recorded bilaterally with paired unipolar micro electrodes (2 mm sintered disks with shielded carbon cable, TMS International BV, Oldenzaal, The Netherlands) placed 2 cm apart along the muscle fibers and a ground electrode was placed on the ulna. The skin was shaved if necessary and cleansed with rubbing alcohol, a conductive gel was applied, and adhesive tape was used to avoid tension on the electrodes (Hermens et al., 2000). Subjects then applied muscle contractions to ensure correct electrode placement and eliminate crosstalk. Electrodes were adjusted if activity of adjacent muscles was detected. The sternocleidomastoid (SCM), splenius capitis (SPL), and semispinalis capitis (SS) muscles were recorded with a sample rate of 2000 Hz.

2.1.3. Tremor assessment

Several patients demonstrated indications of tremulous movement during clinical prescreening prior to participating in this study. A short experiment was therefore conducted to assess levels of dystonic tremor (Deuschl et al., 1998) by fixing subjects in a chair while the head was free to move. Three-dimensional kinematic data of the head was recorded with six markers at 200 Hz using an Oqus 6-camera motion capture system (Qualisys AB, Gothenburg, Sweden), following methods of a previous study (Forbes et al., 2013).