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Measuring regularity of human postural sway using approximate entropy and sample entropy in patients with Ehlers–Danlos syndrome hypermobility type

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ABSTRACT

Ligament laxity in Ehlers–Danlos syndrome hypermobility type (EDS-HT) patients can influence the intrinsic information about posture and movement and can have a negative effect on the appropriateness of postural reactions. Several measures have been proposed in literature to describe the planar migration of CoP over the base of support, and the most used in clinical field are the CoP excursions in antero-posterior and medio-lateral direction. In recent years a growing number of studies have been designed to explore the complexity of the COP trajectories during quiet standing. We assessed 13 adults with EDS-HT (EDSG) and 20 healthy adults (CG) during static posture, evaluating the CoP using time and frequency domain analysis and entropy analysis (SampEn and ApEn parameters). Higher values of CoP displacements in medio-lateral and anterior–posterior directions for EDSG than CG were found; no differences were observed in CoP frequency. The entropy analysis showed lower value for EDSG than CG, pointing out the needing of EDSG to concentrate more attention on postural control, loosing complexity and reflecting a less automatized postural control.

1. Introduction

Joint hypermobility syndrome (JHS) is a relatively common, although largely under diagnosed clinical entity, characterized by congenital contortionism and additional musculoskeletal complaints (Steinmann, Royce, & Superti-Furga, 2002). There is a significant clinical overlap with various heritable connective tissue disorders, mainly the Ehlers–Danlos syndrome(s) (EDS) (Grahame, Bird, & Child, 2000). These similarities are so stringent that, recently, an international group of experts stated that JHS and EDS hypermobility type (EDS-HT) are the same clinical entity that should be distinguished from other types of EDS (Tinkle et al., 2009). Major features include joint hypermobility, joint complications and minor skin features (e.g., skin hyperextensibility), while the presence of additional cutaneous, vascular, skeletal and ocular findings moves towards the diagnosis of other EDS variants. Hypotonia in EDS-HT patients can influence the intrinsic information about posture and movement and can have a negative effect on the appropriateness of co-contraction and postural reactions. Increased joint mobility may contribute in a negative sense to postural control: hypermobility may affect the stability based on faulty reflex pattern originating from tendon organs (Røgind, Lykkegaard, Bliddal, & Danneskiold-Samsøe, 2003). Together with

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insufficiency of co-contraction this will influence the stability of joint. Their impaired postural control (Galli, Cimolin, et al., 2011; Galli, Rigoldi, et al., 2011; Stanitski, Nadjarian, Stanitski, Bawle, & Tsipouras, 2000) tends to progressively worsen as the clinical picture advances, severely limiting the patients' quality of life; as balance represents a key function for performing daily life tasks, its quantification represents a milestone for planning appropriate rehabilitation interventions.

Among the several experimental techniques available to investigate postural control in quiet standing, platform posturography is the most widely used: force platforms measure the fluctuations of the centre of pressure (CoP), which represents the point of contact under the feet through which the ground reaction forces are considered to act. In particular, static posturography is very easily to be acquired in everyday practice, especially in pathological conditions, for the simplicity of the experimental set-up and its safety. Several measures have been proposed in literature to describe the planar migration of CoP over the base of support, and the most used in clinical field are the CoP excursions in antero-posterior and medio-lateral direction.

In recent years a growing number of studies have been designed to explore the complexity of the COP trajectories during quiet standing. Given that during quiet stance the displacements of the COP display highly irregular and non-stationary fluctuations, the analysis of COP dynamics could contain and consequently add information about the postural control exerted. The quantification of the complexity or chaos, in terms of irregularity, could be measured using entropy, defined as a quantity measuring the rate of generation of information (Roerdink et al., 2011a; Roerdink, Hlavackova, & Vuillerme, 2011a, 2011b). In literature, several algorithms were proposed for estimating entropy of a system from a time series. In particular, Pincus (1991) developed a family of statistics, namely the approximate entropy (ApEn index), which has the advantage to be apply both to deterministic and stochastic systems, so in a variety of contexts. This feature makes this parameter one of the most popular metrics used to estimate complexity and regularity in the field of biomedical signal analysis (Aboy, Cuesta-Frau, Austin, & Mico-Tormos, 2007; Pincus & Singer, 1998). However, this method has some biases: firstly it is dependent on the record length and it is lower than expected for short records; then it lacks relative consistency (Richman & Moorman, 2000). To solve these problems, more recently, Richman and Moorman (2000) modified the ApEn method and developed a new parameter, the sample entropy (SampEn index). The SampEn parameter is independent of the record length, is characterized by relative consistency and its algorithm is simpler than the ApEn, needing lower time for computation (Ramdani, Seigle, Lagarde, Bouchara, & Bernard, 2009).

In recent literature, several studies have been addressed to characterize the effects of a broad set of functionally relevant factors on postural stability: these proposals were based on the empirical findings that COP trajectories were more regular (low value of measured entropy) for pathological groups than for controls and on the assumption that COP fluctuations provide a complex output signal of the postural control system in which various pertinent cognitive, perceptual and motor processes are reflected. Roerdink et al. (2006) proposed a direct relation between the amount of attention used in maintaining postural control and the regularity of COP signal: according to their findings, COP trajectories were more regular in stroke patients than in controls and became less regular when performing a secondary cognitive task while standing, reflecting that the measure of the complexity or irregularity of a system is linked to the concept of efficiency or automaticity of postural control. More regular posturograms are associated with increased attentional investments in postural control, in other words, more regular COP signals reflect less automaticity. A decrease in complexity of a physiological time series is indicative of a decrease in healthiness of effectiveness of the physiological control system (Donker, Roerdink, Greven, & Beek, 2007; Goldberger et al., 2002): increased COP regularity may be explained as an indication of an increasingly ineffective postural control strategies.

Starting from these assumptions, several authors reported that through the computation of entropy has been possible to assess specific postural behaviours induced by age, health status, postural task and cognitive contexts (Donker et al., 2007; Ramdani et al., 2009; Roerdink et al., 2006; Stins, Michielsen, Roerdink, & Beek, 2009). In particular, in a more recent study, Roerdink et al. (2011a, 2011b) reported the effects of plantar flexor muscle fatigue on the regularity of COP signal: their finding was that anterior–posterior COP fluctuations were more regular with than without fatigued of plantar-flexor muscles. According to the previously proposed relation between COP regularity and the amount of attention, the authors suggested that standing quietly upright with fatigued plantar flexors may be manifested by a deliberate increase in sway magnitude to indirectly evocate and to exploit the vestibular system, which is accompanied by an increased attentional investment to closely monitor and control posture.

According to these findings and given that the EDS-HT patients are characterized by an increased joint mobility that may contribute in a negative sense to postural control in terms of proprioceptive feedback, in this study we expect to observe larger COP fluctuations for EDS-HT patients than for controls, quantified by the conventional posturographic measures both in time and frequency domain, and to observe a loss of complexity (and consequently automaticity) in the postural control reflecting an increased ineffective postural control strategies with attentional investments in evoking vestibular control, quantified by the measure of approximate and sample entropy.

2. Materials and methods

2.1. Participants

We enrolled 20 individuals as controls (control group: CG) and 13 EDS-HT adult patients matched for age. Exclusion criteria for the CG included prior history of cardiovascular, neurological or musculoskeletal disorders. They showed negative