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Effect of increasing difficulty in standing balance tasks with visual feedback on postural sway and EMG: Complexity and performance

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ABSTRACT

Studies about the relationship between complexity and performance in upright standing balance have yielded mixed results and interpretations. The aim of the present study was to assess how the increasing difficulty in standing balance task affects performance and the complexity of postural sway and neuromuscular activation. Thirty-two young healthy participants were asked to stand still on a stability platform with visual feedback in three levels of difficulty. EMG signals from gastrocnemius medialis, tibialis anterior, rectus femoris and biceps femoris were measured with surface electromyography. As task difficulty increased, the amplitude of postural sway also increased. In the antero-posterior axis, Fuzzy Entropy (complexity) of postural sway decreased from the stable condition to the medium instability condition, and increased again at the highest instability condition. Fuzzy Entropy in the medio-lateral axis was higher in the stable condition; however, no differences were observed between the two instability conditions. Lower values of Fuzzy Entropy in postural sway during stable condition correlated with greater percent increases in postural sway in medio-lateral and antero-posterior axis from the standing still condition to the highest instability condition. In addition, mean and coefficient of variation of EMG increased and Fuzzy Entropy of EMG decreased when the difficulty in standing balance tasks increased. These results suggest that the higher postural sway complexity in stable condition, the greater capacity of the

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postural control system to adapt to the platform instability increases. In addition, changes in the complexity of EMG modulated by task difficulty do not necessarily reflect similar changes on postural sway.

1. Introduction

The maintenance of upright standing posture is a fundamental motor act that provides the basis for locomotion and most other movement tasks (Vaillancourt & Newell, 2002). The postural control system regulates the body's postural sway in upright standing through the complex interaction of somatosensory, visual and vestibular sensory feedback networks, numerous brain regions, and the musculoskeletal system (Manor et al., 2010; Palmieri et al., 2003; Winter, Patla, & Frank, 1990). So "complexity" is defined as the number of system components and coupling functions (interaction) among them (Newell & Vaillancourt, 2001). This can be observed in the upright standing posture through fluctuations of postural sway (Lipsitz, 2002; Manor et al., 2010; Thurner, Mittermaier, & Ehrenberger, 2002).

Numerous authors have suggested that complexity is related to the capacity of the system to generate adaptive responses to stressors (Goldberger, 1996; Goldberger et al., 2002; Lipsitz, 2002). In this sense higher system complexity is connected to a better performance. Therefore, a loss of complexity is thought to be linked to a reduced ability to adapt (Goldberger, 1996; Manor et al., 2010). This takes place when the difficulty of the task increases or when there is a motor control deficit (Seigle, Ramdani, & Bernard, 2009). These conditions caused a reduction in the number of individual structural components making up the system or an alteration in the coupling between components (Goldberger et al., 2002; Newell, 1998; Vaillancourt & Newell, 2002). These results have led to the general hypothesis that a higher complexity of the biological signals is associated to healthy systems, while there is a loss of complexity with aging and disease (Borg & Laxåback, 2010; Goldberger, Peng, & Lipsitz, 2002; Goldberger, Rigney, & West, 1990).

Nevertheless, there are studies which do not support this hypothesis (Borg & Laxåback, 2010; Duarte & Sternad, 2008; Vaillancourt & Newell, 2002). So, for example, in some studies that have examined the relationship between complexity and aging in stability tests, they have found that aged people in addition to having a worse performance in these tests. That is to say, they showed a more complex response than young people in the postural stability control (Borg & Laxåback, 2010; Duarte & Sternad, 2008). Based on these results, and in contrast to the initial hypothesis, high complexity levels may be taken as signs that the system is becoming less sustainable. This is close to the traditional interpretation of entropy as a measure of disorder and noise (Borg & Laxåback, 2010).

Vaillancourt and Newell (2002) suggest that there is not a universal increase or decrease in complexity with age and disease. Rather, the directional change in complexity is dependent on the dimension of the intrinsic dynamic of the behavioral or physiological system. These authors suggest a bidirectional complexity hypothesis that postulates that tasks with a stable equilibrium point show an increase in complexity are highly correlated with enhanced performance, in contrast to tasks with limit cycle stability that show a decrease. In this way, Newell and Vaillancourt (2001) have shown that more degrees of freedom are employed by subjects when trying to maintain a constant isometric force output than during the production of a force sine-wave. On the other hand, Morrison, Hong, and Newell (2007) suggest the possibility that the introduction of more degrees of freedom generally opposes the requirements of the task, finding a higher complexity displacement of center of pressure (COP) when trying to carry out tasks that require the use of a higher number of muscular groups.

Most of the studies that have analyzed the relationship between complexity and performance in balance standing tasks have limited their analysis mainly to postural sway. Therefore, many of them focus on observing the complexity of COP displacement, while only a few have analyzed the complexity of variables such as the activation of muscles involved in postural sway. It is important to examine whether the properties of the EMG for individual muscles will be altered in a similar fashion to that of