Effect of Changing Stability Conditions on Approximate Entropy of Center of Pressure During Quiet Standing

Natalie Tipton[1], Gordon Alderink[2], Samhita Rhodes[1],
[1]School of Engineering, Grand Valley State University, Grand Rapids, MI, USA
[2]Department of Physical Therapy, Grand Valley State University, Grand Rapids, MI, USA
Email: tiptonna@mail.gvsu.edu

Introduction

The physiological processes involved with keeping a human upright are complex and dynamic. A metric commonly used to quantitatively analyze postural control is center of pressure (COP). In order to maintain balance during quiet standing, this factor follows a general oscillatory pattern where it sways about the center of mass (COM) to counteract a potential fall that could otherwise be caused by the COM moving beyond the base of support [1]. The primary objective of this research was to determine whether approximate entropy (ApEn), which quantifies the regularity of a signal [2], could be capable of quantifying changes in stability in typical individuals when implemented on COP signals during quiet standing under increasing levels of instability. We hypothesized that as stability decreased ApEn would increase, indicating less predictability in the postural control mechanism.

Methods

Six healthy individuals (4 females; 24.8±3.3 yrs; 170.8±10.5 cm; 71.0±13.5 kg) participated. Approval was obtained from the Grand Valley State University Human Research Review Committee (#18-246-H). A Full-Body Plug-in-Gait model was utilized in conjunction with 16 Vicon MX cameras (120 Hz) and Nexus motion capture software v2.9.2 (Oxford Metrics) to track anatomical marker trajectories, which were filtered with a 15 Hz Woltring filter. Ground reaction forces were collected using floor-embedded AMTI (Advanced Mechanical Technology Inc.) force plates (1200 Hz) and were filtered with a 6 Hz Butterworth filter. Data were collected for 30 seconds over 5 trials with participants standing with arms flexed, hands touching shoulders, on two force plates under six conditions, from most to least stable: 1) eyes open feet together (EOFT), 2) eyes closed feet together (ECFT), 3) eyes open dominant foot on rear plate (EODB), 4) eyes closed dominant foot on rear plate (ECDB), 5) eyes open dominant foot on fore plate (EODF), and 6) eyes closed dominant foot on fore plate (ECDF). Participants were asked to stand with knees extended, while maintaining equal distribution of weight on each force plate for tandem foot stances. Custom Python code (Python Software Foundation) was used to determine the combined (from the rear and fore force plates) COP location [1]. ApEn was used to quantify changes in stability in antero-posterior (AP) and medio-lateral (ML) directions. Estimation of ApEn requires carefully choosing the parameters m (data length) and r (filter or tolerance level). We selected $m = 2$, as suggested by Pincus [2]. However, the choice of r largely depends on the data itself and so is less standardized. We chose $r = 10$ based on empirical observation.

Results and Discussion

Five of the six subjects showed a significant difference ($p<0.01$) in ApEn between one or more stability conditions. For all of these subjects, a 2-sided Dunnett's post-hoc test showed that every tandem foot position was significantly different from the most stable, EOFT condition in both ML and AP directions (Figure 1), which is supported by previous research [3,4]. ApEn was also able to determine significant differences between eyes open and eyes closed variants of the feet together position on multiple occasions. This suggests that ApEn can be used as a sensitive indicator of stability in postural control. Changes in ApEn between stability conditions did not appear to differ significantly between the AP and ML directions.

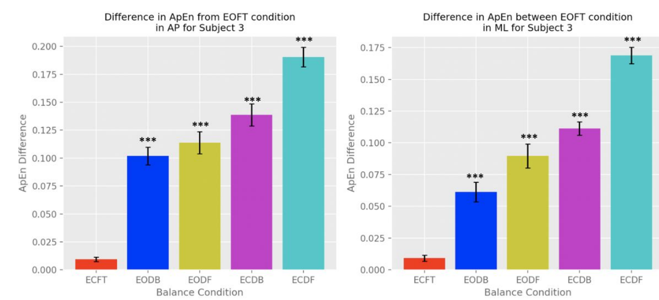

Figure 1. Difference in approximate entropy for each stability condition from most stable, eyes open feet together, position where *** denotes a significance of $p<0.001$, for representative subject.

Significance

It is known that postural control is affected by injuries to the brain [5,6]. Additional information gained from ApEn on the COP provides insight into patterns and indices that are characteristic of a typical brain and how it works to maintain balance. Understanding how an uninjured brain works to keep a person upright during different stability conditions is invaluable for future research with subjects that have suffered from a traumatic brain injury such as a concussion. Our data suggest that ApEn is a metric that can distinguish less stable postural control in healthy individuals. These findings will allow for comparison between the way a typical brain and a damaged brain react to the same quiet standing conditions, and may lead to eventual conclusive testing for concussion diagnosis.

References

[1] Winter, D. (1995), *Gait Posture*, 3, pp. 193–214.
[2] Pincus, S. (1995), *Chaos Interdiscip. J. Nonlinear Sci.*, 5, pp. 110–117.
[3] Cavanaugh, J. et al. (2007), *J. NeuroEng. Rehabil.*, 4, p. 42
[4] Sabatini, A. M. (2000), *Med. Biol. Eng. Comput.,* 38, pp. 617-624
[5] Rochefort, C et al. (2017), *Orthop. J. Sports Med.*, 5.
[6] Catena, R.D. et al. (2009), *J. NeuroEng. Rehabil.*, 6, p. 25.