NONLINEAR ANALYSIS OF POSTURAL CONTROL IN DIFFERENT POSITIONS AND VISION CONDITIONS

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INTRODUCTION

Despite postural control being a multi-degree-of-freedom mechanical system with highly redundant actuators [1], recent research has demonstrated that postural sway fluctuations like fluctuations present in many other biological systems are not random but rather have order [2]. Unlike traditional linear measures which can mask patterns present during postural sway, nonlinear analysis measures can characterize this order. Quantifying these patterns could enable the pinpointing of the precise contributions of sensory input and the improvement of rehabilitation methods [3]. Our aim was to compare the ability of traditional linear measures to nonlinear measures in differentiating between sitting and standing in the presence or absence of visual information.

METHODS

Eleven healthy young adults were asked to 1) stand quietly on a force platform (10 Hz) looking forward (STAND), 2) sit in a yoga style position directly on the force platform with their hands in their laps (SIT), and 3) sit upright on a stool (base 32x34 cm, height 75 cm) placed in the middle of the force platform with their arms to their sides and their feet not supported by the ground or the stool (SITSTOOL). Each position was maintained for five minutes and repeated three times with eyes open and three times with eyes closed. The coordinates of the center of pressure (COP) in the medial-lateral (ML) and anterior-posterior (AP) were calculated for each trial. Then, the unfiltered COP coordinates were analyzed using Chaos Data Analyzer Professional software to calculate four nonlinear measures (Correlation Dimension CoD, Lyapunov Exponent LyE, Hurst Exponent H, and the Lyapunov Exponent after the time series were surrogated SLyE) [2]. To calculate H, all data were first integrated. To calculate our nonlinear measures, we first reconstructed the state space by estimating the embedding dimensions (ED). ED is a measure of the number of dimensions needed to unfold a given attractor. This parameter was calculated with the Tools for Dynamics software [2]. We also calculated five linear measures (Root Mean Square RMS, Mean Distance MD, Total Excursion TE, Mean Velocity MV, and mean Total Excursion per second TEt) [5]. Statistical analysis was performed by either paired t-tests or ANOVA with further post hoc analysis when necessary.

RESULTS AND DISCUSSION

No significant differences were found for ED (mean=4.83). Thus ED equal with 5 was used for all subsequent nonlinear calculations. Our results showed that postural sway fluctuations for all postures examined had deterministic nature (paired t-tests; mean LyE=0.245, SLyE=0.268, $p<.0005$). A system is shown to have deterministic nature (orderly fluctuations), if the LyE is positive and is significantly different than SLyE [2]. We also found a mean H=1.005331 with no significant differences between conditions or directions (paired t-tests). H is a measure of persistence (memory) of a given fluctuation in a time series. This H value suggests that the deterministic patterns in posture have long range memory similar to the 1/f noise found in heart rhythms [4]. We also found that nonlinear measures were able to better differentiate between sitting and standing. LyE (a measure of local stability, higher stability equals smaller LyE) in the ML and CoD (a measure of degrees of freedom) in ML and AP demonstrated significant differences between STAND and SIT ($p=.002$, $p=.002$, $p=.003$) and STAND and SITSTOOL ($p=.007$, $p<.0005$, $p=.003$). Significant differences were also found between STAND and SIT in the linear measures of TE, MV, and TEt in the AP ($p=.034$, $p=.034$, $p=.034$) and TE, MV, TEt, and MD in the ML ($p=.004$, $p=.004$, $p=.004$, $p=.004$, $p=.020$). In addition significant differences were exhibited between SIT and SITSTOOL for the linear measures TE, MV, and TEt in the AP ($p=.001$, $p=.001$, $p=.001$) and ML ($p=.002$, $p=.002$, $p=.002$). Curiously, no differences were found in the linear measures between STAND and SITSTOOL which suggests that it was the distance from the center of gravity to the force platform that influenced the linear measures, rather than characteristics of the COP time series itself. Also, while the linear measure values were different, they measured the same relationships (identical p values). However when differentiating between vision conditions the nonlinear measures performed poorly while the linear measures demonstrated some differences. Only RMS and TEt in the ML showed significant differences between eyes open and closed ($p=.036$, $p=.018$). However significant interactions were found in TE, MV, and TEt in both AP ($p=.04$, $p=.038$, $p=.038$) and ML ($p=.018$, $p=.018$, $p<.0005$) and LyE in ML ($p=.027$). With the exception of TE and TEt in the AP, these interactions were the result of the eyes open values being larger than the eyes closed values during STAND, while the eyes open and eyes closed values were the same in both sitting conditions. This may be due to differing use of sensory information, while maintaining upright standing vs. sitting. There was also a discrepancy in the general trends found in the data. MD and RMS in AP, CoD and H in ML increased from eyes open to eyes closed, while TE, MV, LyE, CoD, and H in AP and RMS, MD, TE, MV, and LyE in ML decreased from eyes open to closed. This is not altogether surprising as Chiari et al. [5] found that while most subjects' sway increases with their eyes closed, there exists a second class of individuals who sway less with their eyes open. In conclusion, the results demonstrated that posture is deterministic and persistent and that nonlinear tools are able to pierce into the structure of posture. However, more work needs to be done to determine whether these tools can contribute to sensory understanding.

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