APPROXIMATE ENTROPY IS ROBUST TO NON-STATIONARITY IN ANALYSIS OF INFANT SITTING POSTURAL SWAY

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INTRODUCTION

Upright sitting is one of the first developmental milestones an infant achieves in normal development. This seemingly static posture involves considerable subtle movement as the weight shifts, requiring specific behavioral control strategies to keep the body upright. Center-Of-Pressure (COP) data obtained from a force platform is used to gain insight into these control strategies (Harbourne & Stergiou, 2003). However, suitable mathematical techniques must be employed to quantify the postural control information from the COP data. Techniques such as path length or range of movement can be used to describe how much the center of pressure moves around (quantity of movement), but these techniques don't give any information about how well coordinated the movement is (quality of movement). Approximate entropy (ApEn) is a measure of the randomness in a time series, and can be used to assess quality of movement. However, stationarity is often a concern in the analysis of time series data, and was an explicit assumption in the derivation of the commonly used ApEn algorithm (Pincus, 1991). Differencing is a commonly employed method for removing nonstationarity from time series data (Chatfield, 2003). Thus, we have explored the use of differencing on the approximate entropy analysis of infant sitting COP data.

METHODS

Infants were recruited when they were just developing the ability to sit upright (started at age 145.1 days old, *sd*=15.9 days, n=11). Infants were screened for normal development by a physical therapist prior to admission into the study, being excluded if they failed to score above 0.5 standard deviations below the mean on the Peabody Developmental Motor Scales (Folio & Fewell, 2000). Infants came to the laboratory twice per month for a period of four months, until they were beginning to crawl, and would thus no longer sit still for data acquisition.

For data acquisition, infants sat on an AMTI force plate (Watertown, MA), interfaced to a computer system running Vicon data acquisition software (Lake Forest, CA). COP data was analyzed using custom MatLab software (MathWorks, Nantick, MA), and ApEn was calculated using code developed by Kaplan and Staffin (1996), implementing the methodology of Pincus (1991) and Kaplan et al (1996). Stage of sitting was assessed by a physical therapist on a scale of 1 to 3 (1=prop sitting, 3=extended time in upright sittting) based on the length of time the infant was able to maintain upright sitting without a fall. ApEn was calculated for the COP data from the anterior-posterior axis for each of 244 trials, both with and without differencing. Differencing is calculating the difference between each data point and the data point preceding it in the time series, reducing the length of the time series by one. The ApEn

results were then correlated with 1) age of the infant at data acquisition, and 2) stage of sitting.

RESULTS AND DISCUSSION

Differencing the data appears to remove most, if not all, of the nonstationarity in the data (Figure 1).

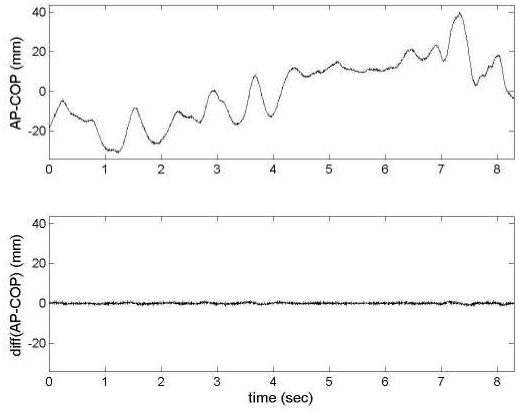

Figure 1: Representative COP time series data in anterior-posterior axis (top) and that same data after differencing (bottom). Differenced data appears more stationary than raw data.

Correlation coefficients of ApEn with developmental variables were larger in magnitude when no differencing was used, and largest when lag 4 was used in the ApEn calculation (Table 1). This is likely due to the presence of 60 Hz noise in the 240 Hz data.

SUMMARY/CONCLUSIONS

Approximate entropy originally was derived as being applicable only to stationary processes (Pincus, 1991). However, one can examine the necessity of this requirement by differencing the data to remove nonstationarity (Chatfield, 2003). Our results indicate, that for postural sway data, differencing is not beneficial. Approximate entropy appears to be robust to nonstationarity of the data.

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Table 1. Correlation coefficients of ApEn with age and with stage of sitting.

Differencing used	none	none	1	4
Lag used in ApEn	4	1	1	1
r (ApEn w/ age)	-0.315	-0.166	-0.124	-0.031
r (ApEn w/ sit stage)	-0.437	-0.251	-0.198	-0.173