MULTISCALE ENTROPY IDENTIFIES COMPLEXITY CHANGES IN POSTURAL CONTROL OF ADOLESCENT IDOPATHIC SCOLIOSIS

[1]Michael A. Busa, Allison H. Gruber, [2]George E. Gorton III,
[2]Peter D. Masso, [1]Joseph Hamill, [1]Richard E.A. Van Emmerik

[1]University of Massachusetts Amherst, MA, USA
[2]Shriners Hospital, Springfield, MA, USA
email: mbusa@kin.umass.edu, web: http://www.umass.edu/biomechanics/

INTRODUCTION

Adolescent Idiopathic Scoliosis (AIS) is characterized by three-dimensional deformation of the spine resulting in alterations of body posture and segment alignment [1]. Changes in body posture have been found to relate to stability deficits in AIS patients, which may be exacerbated by AIS severity [2]. Previous work has related AIS patients have reduced postural stability characterized by requiring greater neuromuscular control to maintain standing balance in the AP direction [4] and increased lateral sway [5].

Traditional measures used to quantify postural control and stability are derived from the center of mass (COM) or center of pressure (COP). Most measures include discrete summary statistics, such as the range, standard deviation or path length.

Investigation of time series rather than discrete measures such as COM or COP parameters, may be important to identify the complexity of the postural control mechanism. Multiscale entropy (MSE) is a measure that examines patterns in time series data at different scaling factors to gain understanding of the spatio-temporal domain in which phenomena occur [3]. It is based on the Sample Entropy (SampEn)[4] algorithm, which assumes stationarity. A reduction in the entropy is associated with a decrease in the complexity of the system. A decrease of complexity is associated with an increase in constraints on the system and a corresponding reduction in the adaptability to meet possible challenges. Reductions in system complexity have been found as a result of the aging process and in various neurological disorders [5].

The purpose of this study was to examine the MSE of COP in the anterior-posterior (AP) and medio-lateral (ML) directions to determine if a loss of complexity is apparent in postural control in AIS. We hypothesized that MSE values would be reduced in AIS compared to controls. Additionally MSE was examined to determine if it could be used to discriminate between severity levels in AIS.

METHODS

Eighteen AIS patients classified as pre-bracing (PB) (12±2 yrs), 18 AIS patients classified as pre-operative (PO) (13±1 yrs) and ten healthy control (CON) subjects (12±2 yrs) were selected from the Scoliosis Clinic patient database at the Clinical Outcomes Assessment Laboratory at Shriners Hospital, Springfield, MA. All subjects were female.

COP position was measured by a force platform at 1080 Hz and during 5s of bilateral quite stance. Data were filtered with a Butterworth low-pass filter with a cut-off frequency of 50 Hz. MSE was used to analyze the complexity of the COP signal in both the AP and ML directions in accordance with the methods outlined in Costa et al [6]. Parameters for the analysis were set at r=0.001 and m=2 for both directions (r was determined by taking 15% of the standard deviation of the time series data). Scale factors 1 through 12 were examined for changes in the spatio-temporal relationship of the pattern of the COP.

A paired sample T-test was used to detect differences between groups (α=0.05). Effect size was also calculated to determine the biological significance of the differences between groups [7].

RESULTS AND DISCUSSION

Paired sample t-tests revealed significant differences ($p<.05$) between the CON and PO groups in both the AP and ML directions of MSE of COP (Tables 1 and 2). For both directions MSE was reduced in the PO AIS group (Table 3). No significant differences were observed between the CON and PB AIS groups. MSE was reduced as a function of disease severity in AIS (Table 3), but this reduction was only significant for the ML direction (Table 1).

Table 1: Paired sample T-test (p-value)

	CON v. PB	PB v. PO	CON v. PO
AP	0.964	0.151	0.009
ML	0.645	0.048	0.040

Effect sizes in between groups (Table 2) show small to moderate effects between all groups in both postural directions.

Table 2: Effect sizes (Cohen's d)

	CON v. PB	PB v. PO	CON v. PO
AP	0.10	0.21	0.37
ML	0.23	0.41	0.21

The advantage of MSE over SampEn is that insight can be gained into the spatio-temporal scale(s) at which physiological phenomena present themselves. The entropy curve in Figure 1 shows the MSE response over multiple time scales (scale factor 1-12). Taking the integral of each curve shows the differences between three groups, which may be hard to distinguish from examining each scale factor separately.

Table 3: Sum of MSE values for scale factors 1-12

	CON	PB	PO
AP	117.324	115.723	112.161
ML	125.198	127.759	121.816

A possible reason for this reduction in MSE, especially in the more severe AIS group (PO), may be a loss of complexity in the dynamics of postural control in people with AIS. The reduction in complexity could be manifested as patients adopt a more rigid control strategy resulting in a more predictable pattern of COP. An important finding is also that the MSE analysis revealed loss of control complexity in COP in both ML and AP directions when comparing more severe AIS (PO group) to controls. Previous research has only demonstrated reduced postural stability in the lateral direction [7]. The reduced entropy in the COP time series in AIS may affect the control of the COM, as previous work has related greater differences between COM and COP in AIS patients to greater demand of neuromuscular control to maintain standing balance [6].

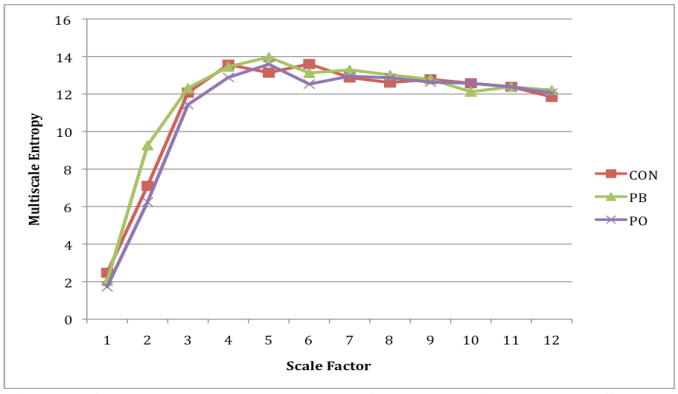

Figure 1: Multiscale Entropy of the Medio-lateral Center of Pressure. Control (CON), Pre-bracing (PB) and Pre-operative (PO)

CONCLUSIONS

MSE analysis revealed decreased entropy in individuals with AIS compared to controls. These decrements were especially present in the more severe AIS group and were observed for both AP and ML postural control. MSE appears to be a powerful tool in distinguishing changes in complexity of the dynamical systems involved in postural control with AIS patients of different severity.

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