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## THE DECAY OF REGULARITY IN POSTURAL CONTROL WITH AGING

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### SUMMARY

Increased postural sway in the elderly has been viewed as a degradation of the postural control system that may be related to an increased risk of falls in the elderly [1]. This study demonstrated the degradation of postural control with aging by quantifying the changes seen in the temporal structure as well as the magnitude of movement of the center of pressure during quiet stance. The analysis of the temporal structure of the center of pressure demonstrated that less of the previous postural position was used to determine the current postural control strategy in elderly subjects. This may explain why elderly subjects demonstrated increased center of pressure movement even though they made more postural adjustments than the younger subjects. Such an analysis approach may be beneficial for future studies investigating the relationship between postural control and fall risk in the elderly.

### INTRODUCTION

Maintaining an upright posture requires the central integration of sensory information from the somatosensory, vestibular and visual feedback systems. It is believed that aging negatively impacts the ability of the body to maintain postural stability due to degraded control systems. This is often interpreted based on findings of increased postural sway with aging during quiet standing [2]. Postural control is often assessed by calculating the path length and the 95% ellipse area of a center of pressure (COP) trace collected while an individual stands on a force platform. However, these measures focus on the gross amount of movement and ignore the temporal structure of the center of pressure signal. As a result, they only provide an indication of the magnitude of the COP movement and do not allow for the interpretation of the dynamic changes in the COP due to the complex sensory-motor integration involved in postural control [3]. It is important to investigate the temporal aspects of the COP time series in order to determine if there is a meaningful structure that may provide information about the underlying control mechanisms [4]. Sample entropy, a variable derived from nonlinear dynamics, is used to analyze the temporal structure by quantifying the amount of regularity present in the structure of the COP signal [5]. The purpose of this study was to determine the effects of aging on the magnitude and temporal structure of the COP movement by observing the transition of the sample entropy from an ordered to a disordered state.

### METHODS

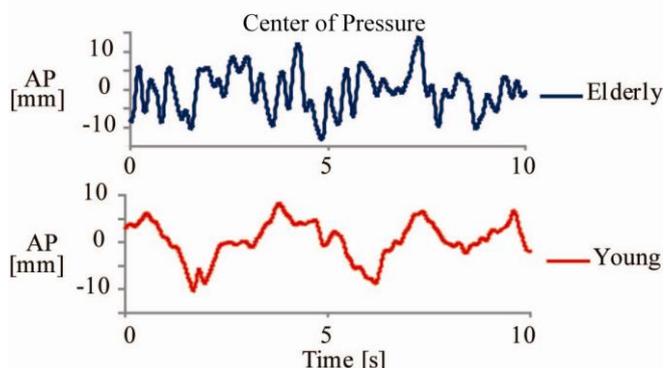
Forty eight subjects (24 elderly, 24 young) participated in this study (Table 1). All subjects were free from injury or pain for at least six months prior to testing. Ground reaction force data was collected at 2400 Hz from a force platform (Kistler Instruments AG, Winterthur, Switzerland) embedded within the laboratory floor as subjects completed single limb stance trials with their dominant limb. Subjects were instructed to stand in the center of the force platform without locking their knees during each of the standing trials. Subjects were asked to keep their arms relaxed down at their sides while focusing on a point directly in front of them at eye level. The location of the COP in the medio-lateral (ML) and anterior-posterior (AP) direction was calculated using the force and moment profiles for the force platform. A wavelet filter was implemented with cut-off frequencies of 0.15 and 10 Hz. The filtered COP signal was then resampled at 75 Hz (dt = 13 ms).

The regularity of the COP signal was quantified by calculating the sample entropy (SampEn) for consecutive gradual randomizations of the original COP time series. Gradual randomization was achieved through successive reshaping procedures of the original time series. For example, for a reshape scale (RS) of 2, the original signal [1 2 3 4 5 6 7 8 9 10 11 12] was reshaped to the new signal [1 3 5 7 9 11 2 4 6 8 10 12]. Similarly, a reshape scale of 3 resulted in a new signal [1 4 7 10 2 5 8 11 3 6 9 12]. The time between two adjacent points in the original signal was 13 ms. After a RS of 2, adjacent points were now 26 ms apart. The SampEn was then calculated for each of the newly reshaped COP time series. Sample entropy provides a measure of the regularity or predictability of a time series, with low values indicating more regularity [6]. SampEn values were normalized to a maximum SampEn representing a completely random COP signal. The SampEn values were then plotted as a function of the common logarithm of the time associated with each reshaping scale. The entropic half-life  $E(1/2)$  was identified as the time at which the SampEn transitions from being more regular to more irregular (SampEn = 0.5). The magnitude of COP movement was quantified using the path length and the 95% ellipse area.

Statistical differences were evaluated using a one-way analysis of variance (ANOVA) with a significance level of  $\alpha=0.05$ .

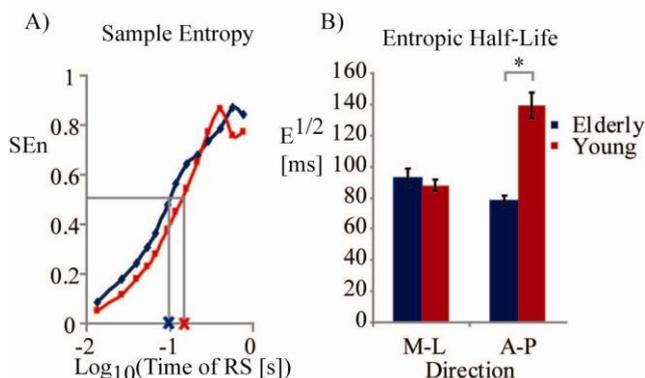
## RESULTS AND DISCUSSION

Visual inspection of the raw COP signal in the AP direction showed that the elderly subjects showed more fluctuations in the COP signal indicating a less regular center of pressure movement compared to the young subjects (Figure 1).



**Figure 1:** Ten-second portion of the raw center of pressure signal in the AP direction for an elderly subject and a young subject.

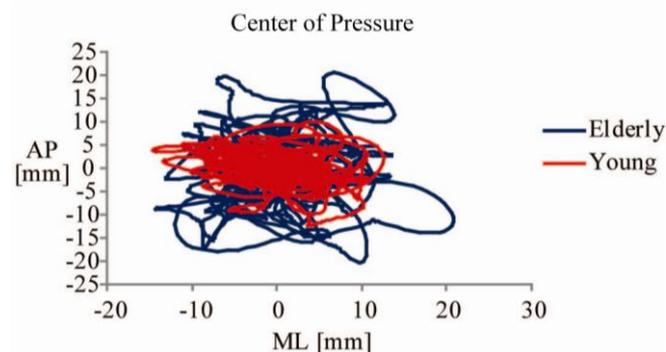
There was no significant difference between the elderly and the young subjects for the entropic half-life in the ML direction. However, the elderly subjects demonstrated a significantly shorter ( $p < 0.001$ )  $E(1/2)$  (mean (SD) – 78 (16) ms) in the AP direction compared to the younger subjects (mean (SD) – 139 (40) ms) (Figure 2).



**Figure 2:** A) Normalized SampEn ( $m = 3$ ,  $r = 0.7$ ) transitions for an elderly subject (blue) and a young subject (red).  $E(1/2)$  is marked with an 'x' on the x-axis. B)  $E(1/2)$  values for the elderly (blue) and young (red) subjects in the ML and AP direction (mean and standard error). Significant differences are marked with an \*.

The elderly subjects demonstrated larger magnitudes of movement compared to the young subjects (Figure 3). Specifically, the elderly subjects had a longer path length (mean (SD) – 1573 (322) mm) compared to the younger subjects (mean (SD) – 1095 (258) mm). Additionally, the elderly subjects demonstrated a larger 95% ellipse area

(mean (SD) – 889 (281)  $\text{mm}^2$ ) compared to their younger counterparts (mean (SD) – 509 (191)  $\text{mm}^2$ ) (Figure 3).



**Figure 3:** Center of pressure trace for an elderly subject (blue) and a young subject (red). Center of pressure location is relative to the mean location ( $x, y = 0$ ).

## CONCLUSIONS

The results from this study demonstrated the reduction in the  $E(1/2)$  in conjunction with an increase in the movement magnitude of the COP during quiet standing with aging. The shorter  $E(1/2)$ , found with the elderly subjects, may be interpreted as a degradation of the postural control system with reduced ability to predict future states of the COP location based on previous states. This reduced predictability may explain the increased frequency of postural adjustments seen through a less regular COP signal in the elderly. As the motor output recorded with the center of pressure may reflect the underlying motor control mechanisms, it is possible that this reduction may be associated with a degradation of the sensory-motor control system with aging. The results from this study showed that even though elderly subjects demonstrated more frequent postural adjustments, this did not help to reduce the magnitude of movement of their COP during quiet stance. Degradation of the postural control system with aging may have inhibited the ability of elderly subjects to detect and effectively control changes in the COP position, similar to deficits found in postural control following injury. [7].

## ACKNOWLEDGEMENTS

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**Table 1:** Description of elderly and young subjects used for this study.

Age Group	Gender	Sample Size	Age [years]		Height [cm]		Weight [kg]	
			Average	SD	Average	SD	Average	SD
Elderly	Male	13	59.4	2.1	175.3	6.5	87.6	17.0
	Female	11	66.0	4.9	163.0	7.4	72.8	9.4
Young	Male	13	26.1	2.9	176.8	7.8	73.4	8.7
	Female	11	23.8	2.5	166.5	4.9	61.6	6.3