ASSE Foundation Research

# Postural Control

## Age-related changes in working-age men

**By Adam J. Strang and Angela T. DiDomenico**

WORKPLACE FALLS IN THE U.S. resulted in 680 fatalities in 2008, accounting for 13% of all work-related fatalities, according to Bureau of Labor Statistics (BLS, 2010a; b). In addition, nonfatal workplace falls accounted for approximately 21% of all work-related injuries that required days away from work. The direct insured costs of these falls were estimated to be $13.9 billion in 2008 (Liberty Mutual, 2009).

The burden of workplace falls and injuries will likely increase in the coming years because the number of older adults (those age 65 and older) in the U.S. workforce has risen sharply (Mosisa & Hipple, 2006). As adults age, they are generally more likely to experience falls and fall-related injuries (Sattin, Lambert-Huber, DeVito, et al., 1990). In fact, reports indicate that one-third of older adults suffer at least one fall per year (Hausdorff, Rios & Edelber, 2001).

It is generally assumed that the increased incidence of falls as humans age is the result of steady declines in muscular strength, flexibility, reaction time and proprioceptive sensitivity (i.e., the ability to sense the body's relative position and movements) (Schmidt & Lee, 1999), all of which contribute to decreased postural control (Lord, Ward, Williams, et al., 1994; Maki, Holliday & Topper, 1994). Despite this, researchers have not developed a thorough understanding of how postural control changes over one's lifespan, nor have they developed a reliable model from which to predict falls based on laboratory observations of postural control (e.g., postural sway) (Buatios, Gueguen, Gauchard, et al., 2006).

### Defining & Measuring Postural Sway

In laboratory experiments, postural control is often observed by obtaining center of pressure (COP) time-series from a forceplate while participants are engaged in some form of upright stance (e.g., two-leg, single-leg, eyes open, eyes closed). Figure 1 (p. 28) depicts a typical laboratory setup for such a procedure, as well as a two-dimensional birds-eye view of a front/back [anterior-posterior (A-P)] versus left/right [medial-lateral (M-L)] COP position plot obtained during quiet two-legged stance with eyes open. What is evident from this plot is that standing posture is not really quiet at all, but instead contains steady and persistent movement (i.e., postural sway).

Over the past few decades, researchers have attempted to analyze postural sway using several measures, such as COP average velocity, total distance traveled (or path length), range and root mean square (RMS) amplitude. Collectively, these measures provide information about the overall amount of postural sway (e.g., velocity, total distance traveled) or general area (e.g., range, RMS) in which postural sway occurs (Palmeri, Ingersoll, Stone, et al., 2002).

Despite the lack of success using these measures to predict falls, results obtained using this approach have proven successful for examining the effects of several occupational hazards on postural control, such as early childhood exposure to lead (Bhattacharya, Shukla, Dietrich, et al., 2006); prolonged work exposure to jet fuel (Smith, Bhattacharya, Lemasters, et al., 1997); heavy equipment loads (Sobeih, Davis, Succop, et al., 2006); and motion sickness (Smart, Stoffregen & Bardy, 2002).

Recently, researchers have begun to incorporate a new set of measures to assess postural sway with the

**Abstract:** *As adults age, they are more likely to experience falls and fall-related injuries. This is thought to occur as the result of age-related declines in postural control. However, little is known about how, or whether, postural control changes with age in healthy working-age populations. This research examined changes in the postural control using a set of traditional statistical measures and a nonlinear time-series analysis called Sample Entropy. The findings, their implications and future applications for developing models to predict and prevent falls are discussed.*

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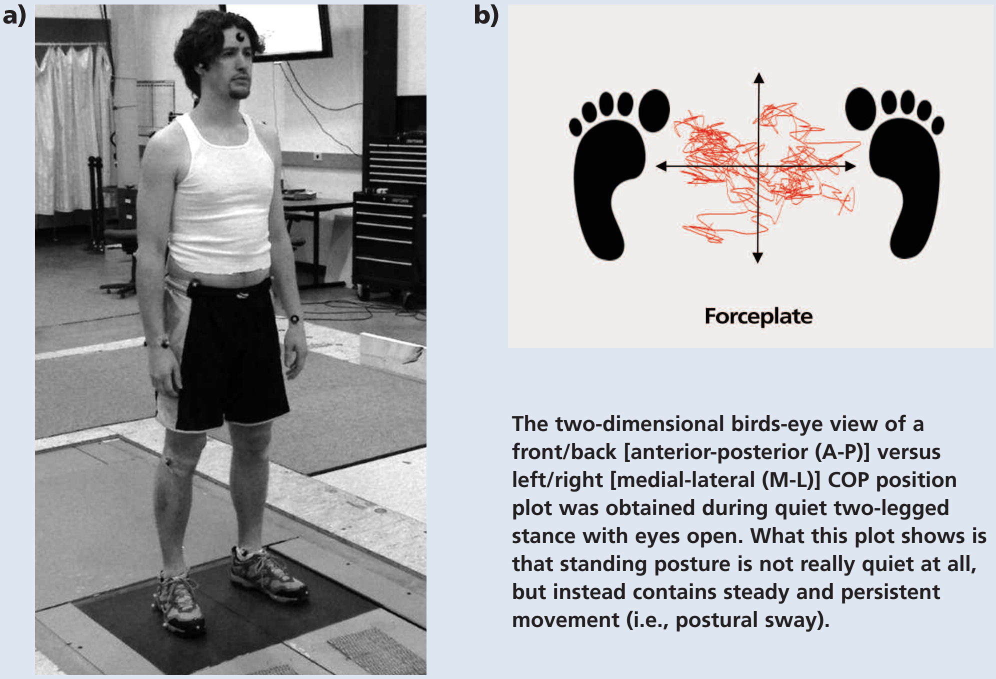
**Figure 1**

**Lab Setup for Postural Control Study**

a) a participant engaged in quiet upright stance on a forceplate; b) a two-dimensional stabilogram plot depicting a "birds-eye-view" of the front/back (anterior-posterior; A-P) versus left/right (medial-lateral; M-L) center of pressure position of the participant in the photo for 15 seconds of continuous stance.



**The two-dimensional birds-eye view of a front/back [anterior-posterior (A-P)] versus left/right [medial-lateral (M-L)] COP position plot was obtained during quiet two-legged stance with eyes open. What this plot shows is that standing posture is not really quiet at all, but instead contains steady and persistent movement (i.e., postural sway).**

hope that these measures may provide new insight into postural control and/or lead to the development of better predictive models of behavioral outcomes (e.g., falls, motion sickness, work fatigue) (Stergiou, Buzzi, Kurz, et al., 2005). These measures are collectively referred to as *nonlinear time-series analyses*.

Nonlinear time-series analyses were developed by mathematicians and physicists in an attempt to capture information about the temporal structure in rhythmic oscillations that are commonly observed in continuous systems such as cardiac rhythm (Richman & Moorman, 2000); electrical brain activity (Diambra, Bastos de Figueiredo & Malta, 1999); machine vibration (Yan & Gao, 2007); walking gait (Papadakis, Christakis, Tzagarakis, et al., 2009); the stock market (Pincus & Kalman, 2004); and postural sway (Cavanaugh, Guskiewicz & Stergiou, 2005). Inherent in the development and use of these analyses is an assumption that the oscillations noted when observing a continuous system's behavior over time are not just random noise, but contain some degree of predictability or determinism (i.e., underlying and lawful causation).

To illustrate how these measures are applied and what unique information they provide, four time-series representing the behavior of four continuous systems often examined with these analyses are presented in Figure 2. A quick glance at these systems with a focus on looking for consistent patterns in each system's temporal structure reveals that these systems have varying degrees of determinism in their rhythms.

Specifically, the sine wave (a mathematical function with a specified frequency and amplitude) appears to contain the most determinism (i.e., it is the most predictable), followed by M-L postural sway and heart rate (both of which seem to have some degree of determinism and randomness), and finally white noise (which by definition is a completely random function akin to the static interference heard when listening to an unclear radio signal).

To support this assessment with a quantifiable metric, the time-series in Figure 2 were subjected to examination using a popular nonlinear time-series analysis known as sample entropy (SampEn). Briefly, SampEn is a measure that attempts to quantify the degree of regularity or complexity within a time-series on a scale from zero (low complexity; associated with a time-series exhibiting high determinism) to two (high complexity; associated with a time-series exhibiting low determinism) (Richman & Moorman, 2000).

SampEn values for the sample time-series illustrated in Figure 2 are presented in Table 1. From these data, one can see that the estimates of complexity provided by SampEn match the perceptions apparent to the naked eye. In fact, SampEn and approximate entropy (ApEn), a closely related measure, have been shown to be some of the most reliable and accurate analyses for describing temporal structure in continuous biological systems (e.g., heart rhythm, hormone secretion) compared to other forms of nonlinear time-series analysis (Pincus, 1997).

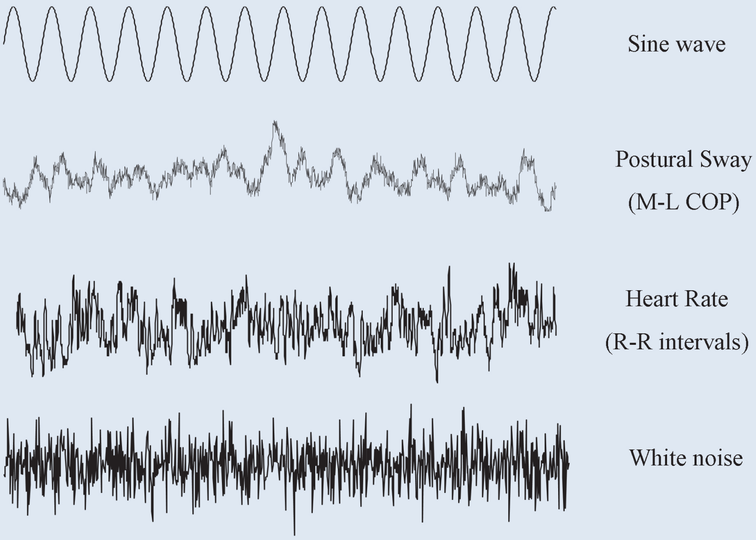
### The Experiment

To date, only a few studies have attempted to use any form of nonlinear time-series analysis to assess changes in postural sway between different age groups (Newell, 1997), and no study has assessed changes in postural sway using these measures with age as a continuous variable. Based on this, the current experiment was designed to investigate whether one nonlinear time-series analysis (SampEn) might prove useful for detecting age-related changes in the postural sway of working-aged men, as well as to compare results obtained from SampEn to a set of more traditional postural sway measures (e.g., COP average velocity, range, position variability) to examine whether SampEn may be more sensitive to and/or provide additional information about age-related changes in postural control that traditional measures do not.

**Figure 2**

## Time-Series of Continuous Systems

Continuous systems with varying degrees of determinism (i.e., predictability) in their oscillations. From visual assessment of these time-series it appears that the sine wave (unitless) contains the most determinism, followed by the M-L postural sway (cm), heart rate (beat-to-beat intervals; sec) and white noise (unitless).



**A quick glance at these systems with a focus on looking for consistent patterns in each system's temporal structure reveals that these systems have varying degrees of determinism in their rhythms.**

To accomplish this, 45 men age 18 to 65, free of musculoskeletal injury/disease or balance disorder, and within a body mass index (BMI) range of 19 to 35, were recruited to participate in a larger study focused on postural control and balance recovery associated with work-related postures (of which this experiment was only one part). Prior to the experimental session, all participants completed an informed consent procedure approved by the Liberty Mutual Research Institute for Safety's Institutional Review Board.

During the experiment, three trials were recorded where participants were simply asked to stand two-legged on a forceplate as still as possible with arms at their sides, shoes on, feet placed shoulders width apart and eyes focused on a target located 7 m away at eye level for a period of 60 seconds. While standing in this position, COP was recorded in the A-P and M-L directions at 100 samples per second. During post-processing, the first 10 seconds of every trial was cropped to eliminate the influence of any movement adjustments participants might have made at the beginning of a trial (leaving 50-second trials for use in later analysis).

Once the COP data for all participants were collected and cropped, the following postural sway measures were derived: SampEn ($M = 2$, $r = 0.2$; unitless value), total distance (cm), average velocity (cm/s), range (cm) and RMS (cm). Following computation of these measures for all trials, the values obtained for each participant (three values per measure) were averaged to minimize the influence of an erroneous trial.

**Table 1**

## SampEn Values

SampEn values corresponding to the time series in Figure 2. Values closer to zero indicate *increased* complexity in the time-series, whereas values closer to two represent *decreased* complexity.

| Time series | SampEn |
|---|---|
| Sine wave | 0.24 |
| Postural sway (M-L COP) | 1.12 |
| Heart rate (beat-to-beat intervals) | 1.16 |
| White noise | 2.17 |

**From these data, one can see that the estimates of complexity provided by SampEn match the perceptions apparent to the naked eye.**

### Experiment Results

A representative M-L COP time-series for an 18-year-old and 59-year-old participant are depicted in Figure 3 (p. 30). As in the earlier example, a quick review seems to indicate that the temporal structures of these time series are quite different. Specifically, it appears that the 18-year-old exhibits postural sway that is less deterministic and, thus, more complex, compared to the 59-year-old.

To assess whether this observation was indicative of a larger trend, a series of correlations were performed investigating the possible linear relationships between age (a continuous variable) and all dependent measures of postural sway used in this experiment (Table 2, p. 31). Results for the 45 participants showed that significant negative linear relationships existed between age and A-P and M-L COP total distance and SampEn, as well as M-L average velocity (Figure 4, p. 32). No significant relationship was found between age and A-P or M-L range or RMS.

Collectively, these results imply that as working-age men get older, they reduce the amount of their postural sway, as well as produce sway that is less complex (indicative of a more deterministic sway pattern). However, the general area in which postural sway occurs does not change.

### Interpreting the Results

The results of this study show that measures providing information about the amount (average velocity and total distance) and temporal structure (SampEn) of sway were able to detect age-related changes in healthy working-age men. This is important information since it confirms that a nonlinear time-series analysis, as well as some traditional sway measures, are useful for detecting age-related changes, and are likely important components to include in predictive models of human postural sway over the lifespan.

That said, it is a challenge to decipher exactly what these results mean in terms of improving understanding of how postural control changes over the lifespan and what future application these findings may have for predicting or preventing behavioral outcomes such as falls in the workplace.

For example, traditional perspectives on postural control have assumed that reductions in the amount or area of postural sway are indicators of improved balance and stability (Nashner & McCollum, 1985). From this perspective, one might conclude that since sway area did not get any larger with age and that since the amount of sway was actually reduced, postural control might improve with age. In addition, when these findings are integrated with information provided by SampEn (which showed that postural sway became more deterministic with age), these results seem to imply that not only are men swaying less as they age, they are also swaying in a more predictable manner.

Might this mean that as men age (at least up to age 65) they use their experience to elicit better postural control compared to younger counterparts? While this is possible, it is also possible that it may be misleading to embrace a traditional interpretation of these results. In fact, when looking at these results from a nonlinear/dynamic systems perspective, a somewhat different interpretation is possible. To understand this interpretation, a review of previous research is necessary.

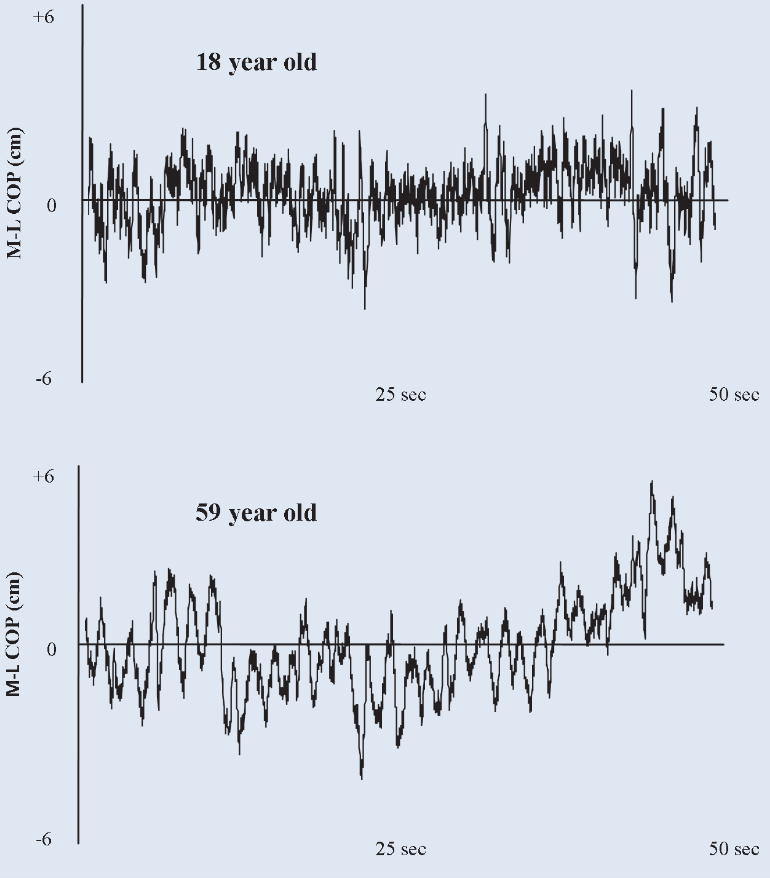
In one study, Schmit, Regis and Riley (2005) compare differences in the postural sway of ballet dancers and track athletes using a nonlinear time-series analysis known as recurrence quantification analysis (RQA). The researchers assume that ballet dancers and track athletes have similar body types, but that ballet dancers, because of the specific requirements of their athletic activity, likely have superior postural control. Results from this study show that ballet dancers exhibit less determinism in their sway than track athletes. (Note: The actual nomenclature used to describe RQA and SampEn are quite different, but similar terms are used here to preserve a consistent interpretation.)

**Review of these data seems to indicate that the temporal structures of these time series are quite different. Specifically, it appears that the 18-year-old exhibits postural sway that is less deterministic and, thus, more complex, compared to the 59-year-old.**

## Figure 3

## M-L COP Time-Series

Representative time series of M-L COP for an 18-year-old and 59-year-old during bipedal stance (50-second trial). From visual assessment of these time series it appears that the 18-year-old's sway is more complex (i.e., less deterministic) compared to the 59-year-old.



In other studies, researchers have shown that patients with Parkinson's disease exhibit more determinism in their sway compared to healthy controls (Schmit, Riley, Dalvi, et al., 2006); that participants standing with eyes closed (conceivably a stance condition that threatens stability) exhibit more determinism in their sway than in eyes open conditions (Donker, Roerdink, Greven, et al., 2007); and that engaging in a distracting mental task (e.g., counting backwards by threes) also results in a more deterministic sway pattern (Pellecchia, Shockley & Turvey, 2005). Finally, Newell (1997) showed that older adults (age 65 to 75) exhibited more determinism in their sway than younger adults (age 18 to 25).

Collectively, the results of

these studies seem to point toward an emerging trend. That is, postural sway in those who are in some way constrained (e.g., patients suffering from disease, those restricted from the use of vision, older adults who might have reduced strength and flexibility) exhibits more determinism in its temporal structure than it does in those who might be considered generally healthy and unconstrained (e.g., young adults, ballet dancers).

**Table 2**

## Correlations: Age & Postural Sway

Correlations between age and postural sway measures, as well as descriptive means for each sway measure for participants on opposite ends of the age spectrum (i.e., men ages 18 to 24, and 56 to 65).

| Measure category | Postural sway measure | Age correlations (Pearson's *r*) | Mean values 18 to 24 year olds (*N* = 10) | Mean values 56 to 65 year olds (*N* = 10) |
|---|---|---|---|---|
| "Area" of postural sway | A-P range (cm) | 0.24 | 3.15 | 4.15 |
| | M-L range (cm) | -0.12 | 11.60 | 12.01 |
| | AP RMS (cm) | 0.10 | 0.65 | 0.65 |
| | ML RMS (cm) | -0.02 | 0.20 | 0.18 |
| "Amount" of postural sway | A-P total distance (cm) | -0.44[a] | 19.10 | 15.49 |
| | M-L total distance (cm) | -0.46[a] | 17.72 | 13.85 |
| | A-P average velocity (cm/s) | -0.28 | 0.21 | 0.18 |
| | M-L average velocity (cm/s) | -0.48[a] | 0.19 | 0.15 |
| "Temporal structure" of postural sway | A-P SampEn (unitless) | -0.40[a] | 0.29 | 0.19 |
| | M-L SempEn (unitless) | -0.33[b] | 0.90 | 0.71 |

***Note.*** [a] $p < 0.01$; [b] $p < 0.05$.

This has led researchers to theorize that healthy and/or unconstrained postural sway may contain a small, but important amount of *chaotic variability* within its rhythmic oscillations. This variability has been hypothesized to reflect flexibility, the potential for adaptability or even exploratory postural control (Newell, 1997; Pellecchia, et al., 2005; Schmit, et al., 2005). Conversely, unhealthy and/or constrained postural sway appears to be more periodic and predictable, which has been thought to reflect a more rigid and/or tightly controlled sway strategy (Donker, et al., 2007).

What remains unknown is whether a more tightly controlled sway strategy is indicative of a functional adaptation that attempts to preserve postural performance despite the presence of a constraint (possibly by attempting to exert more conscious control over postural sway) or simply reduced stability.

While results from the present experiment cannot answer this lingering question, this experiment lends support to the current research trend provided one is willing to assume that age represents a negative constraint on postural control. This study also adds something unique to the literature by observing changes in postural control as a continuous function of age in a rarely researched demographic (i.e., healthy men within the traditional working ages of 18 to 65).

Still, one must recognize that this study was preliminary and had several important limitations. For example, the sample size was relatively small ($N = 45$); women were not included; researchers did not examine postural sway in adults older than age 65; the research team did not attempt to control for other factors that might affect postural control (e.g., physical fitness level); and the team did not assess postural sway in more challenging work-related postures (e.g., squatting, reaching). Future research will address these limitations.

## Application & Future Research

The goal for much postural research is to develop ways to predict and prevent fall-related injuries. If researchers can better understand how the dynamics of postural sway are altered by factors known to be associated with falls, such as age, injury, physical fitness, weight and gender, then it may be possible to someday accurately predict the likelihood of a fall, or provide an assessment of balance recovery following an injury through simple, objective and cost-effective measurement of standing posture. This remains a future goal.

**To assess whether this observation was indicative of a larger trend, a series of correlations were performed investigating the possible linear relationships between age (a continuous variable) and all dependent measures of postural sway used in this experiment.**

The results of this experiment indicate that age-related changes in postural sway are steady and progressive. Taken together, this may mean that balance is not just a challenge for the elderly, but also a factor to consider when implementing safety programs or seeking to improve safety at the worksite where a broader range of ages are likely represented.

It is hoped that the results of this study will motivate more postural control research (specifically among working-age populations), as well as lead to more advanced research using nonlinear time-series analyses to assess postural sway. Furthermore, while the use of these new analyses adds new and perplexing theoretical questions that researchers will have to address, they may ultimately provide the information needed to build better predictive models of postural behavior. ■

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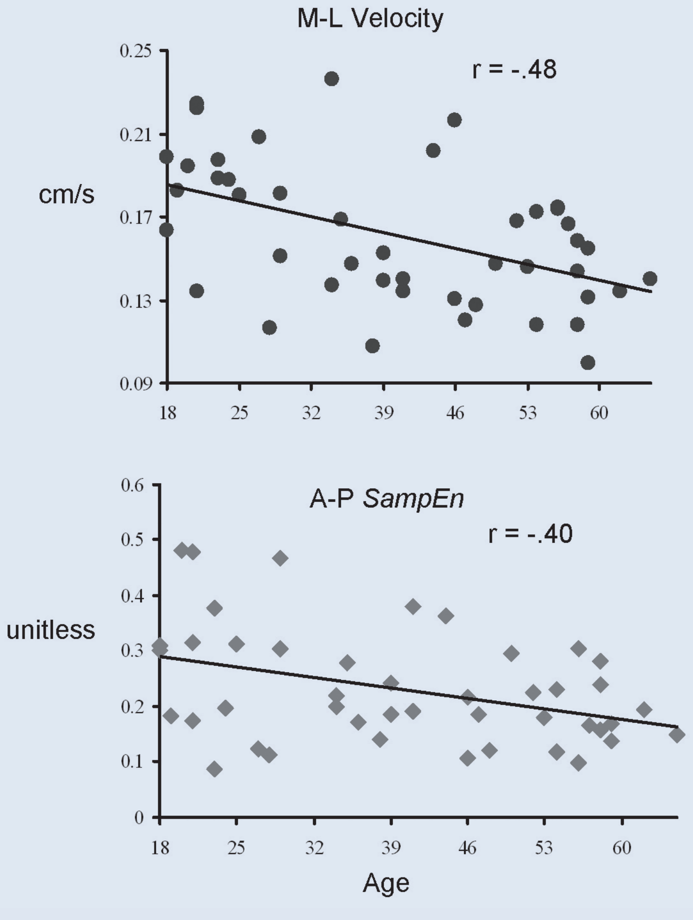
**Figure 4**

## Relationships Among Variables

Scatterplots with trend lines for a) age versus A-P SampEn; and b) age versus M-L average velocity. These plots depict moderately strong relationships (*r* values between 0.4 and 0.5) indicating that postural sway SampEn and average velocity tend to decrease progressively with age.



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