Dear Editor,

We appreciate the thoughtful commentary by Chastin et al regarding our recent article entitled "Nonlinear Analysis of Ambulatory Activity Patterns in Community-dwelling Older Adults."[1] We fully agree with their observation that the application of nonlinear analytical tools to accelerometry data is an emerging area of research that shows potential for illuminating the complex nature of physical activity profiles. We also welcome the opportunity to discuss their concerns regarding (1) our application of detrended fluctuation analysis (DFA), entropy rate (ER), and approximate entropy (ApEn) to natural activity data, and (2) our narrow focus on stepping activity.

Regarding the first concern, we respectfully disagree with their contention that "entropy-based measures of walked minutes time series clearly do not provide an estimate of complexity, independent of activity levels." Consider the 24-hour recordings collected from individual study participants (Figure 1.) In panel A, each person accumulated approximately the same number of steps over the course of a day (3,582 vs. 3,684, % difference[^]. = 2.8.) Yet the complexity embedded in the temporal structure of their activity patterns was distinctly different (DFA α: 0.61 vs. 1.03, % difference = 51.0; ER: 1.76 vs. 2.60, % difference = 38.5; ApEn: 0.1161 vs. 0.2232, % difference = 63.1). Alternatively, in panel B, two individuals each accumulated a distinctly different number of steps (4,682 vs. 12,788, % difference = 92.8). Yet the complexity of their activity patterns was remarkably similar (DFA α:

[^] Percentage (%) difference calculated as (A-B)/((A+B)/2)

0.713 vs. 0.710, % difference = 0.3; ER: 4.26 vs. 4.24, % difference = 0.5; ApEn: 0.4538 vs. 0.4560, % difference = 0.5).

These cases serve as a valuable reminder that while our aggregated data revealed a statistically significant, positive correlation between each complexity estimate and step count, the nonlinear measures individually explained less than half of the variance in activity. Especially at the person-level of analysis, it clearly is not the case that the complexity of activity patterns necessarily is dependent on the volume of activity accumulated. Rather than recommending, as our colleagues did, that complexity estimates require adjustment for activity level, we advocate for a more cautious interpretation of our results consistent with the preliminary nature of the study. The data suggested to us that entropy based measures, and DFA as well, provided sufficiently unique information about ambulatory activity to warrant further investigation.

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INSERT FIGURE ABOUT HERE

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Also related to the first concern, we agree that minute sampled step count series are not equivalent to gait cycle time series in the information they provide. We disagree, however, that the difference between them lies, in part, in the relatively less continuous nature of the step count time series. Both series are sampled at absolutely regular intervals that differ only in terms of duration; both contain sequences of walking-related events that are deterministic in origin, presumably from complex interactions in underlying physiologic systems responsible for their production; and both can be easily captured in sufficient quantity to be suitable for nonlinear analyses.

From our perspective, the primary difference between step count and gait cycle time series lies in the fundamental nature of what each represents. In typical gait cycle measurement protocols, the physical and social environments of the laboratory are artificially fixed, in what arguably may be an unnatural way, so that nonlinear methods can be focused directly on the complexity of physiologic output produced by an individual. In free-living activity monitoring, however, data capture intentionally includes the interaction of an individual with their natural, dynamic environment. In this context, nonlinear analyses (e.g., DFA) are constructed to draw inferences about the complex nature of the individual-environment interaction. Given this distinction, we agree with our colleagues that our data did not reveal much about stride to stride stepping patterns; we believe instead that our data revealed a great deal about the complex nature of how active and inactive older individuals vary their walking patterns throughout the day as they interact with their natural physical and social environments.

Our colleagues' second concern appears to relate to our choice of step counts to provide a representative record of physical activity patterns. The concern, they contend, is especially valid given that human behavior emerges naturally from the interaction of multiple influences and not according to an arbitrary time scale. We agree that our approach, like many other models used to understand human behavior, used a limited lens; indeed, we explicitly listed factors not considered in our interpretation of findings and recognized that “physical activity cannot be inferred from step counts alone.” Importantly, we chose to sample step counts at 1-minute intervals to facilitate comparisons of our data with pedometer-based studies of physical activity.[2]

We do not share our colleagues’ view that because of its multiple influences, the “analysis of sequences of active and sedentary periods promises to be more difficult than gait time series.” Alternatively, we submit that the clinical interpretation of nonlinear analysis applied to ambulatory activity data can be enhanced through the application of broad theoretical views of humans as adaptive systems. According to our previous work,[3] healthy human states are associated with optimal movement variability that reflects the adaptability of the underlying control system. Sequences of naturally occurring active and sedentary periods, which contain movement variability expressed at a behavioral level, are interpreted to reveal the extent to which individuals both adapt to and create changes in their environment.[4] We believe, therefore, that nonlinear analyses of activity fluctuations, by quantifying the complexity of the human-environment interaction, offer potential insight into how healthy, adaptable states are sustained. Said differently, nonlinear analyses might be better suited for determining the characteristics of healthy activity profiles, especially among individuals at risk for functional decline, than for understanding the underlying influences of activity.

Sincerely,

James T. Cavanaugh and Nicholas Stergiou

References

1. Cavanaugh JT, Kochi N, Stergiou N. Nonlinear analysis of ambulatory activity patterns in community-dwelling older adults. *J Gerontol A Biol Sci Med Sci.* Feb 2010;65(2):197-203.

2. Aoyagi Y, Shephard RJ. Steps per day: the road to senior health? *Sports Med.* 2009;39(6):423-438.

3. Stergiou N, Harbourne R, Cavanaugh J. Optimal movement variability: a new theoretical perspective for neurologic physical therapy. *J Neurol Phys Ther.* Sep 2006;30(3):120-129.

4. Andrews HA, Roy C. The Roy adaptation model: the definitive statement. East Norwalk: Appleton & Lange; 1991.

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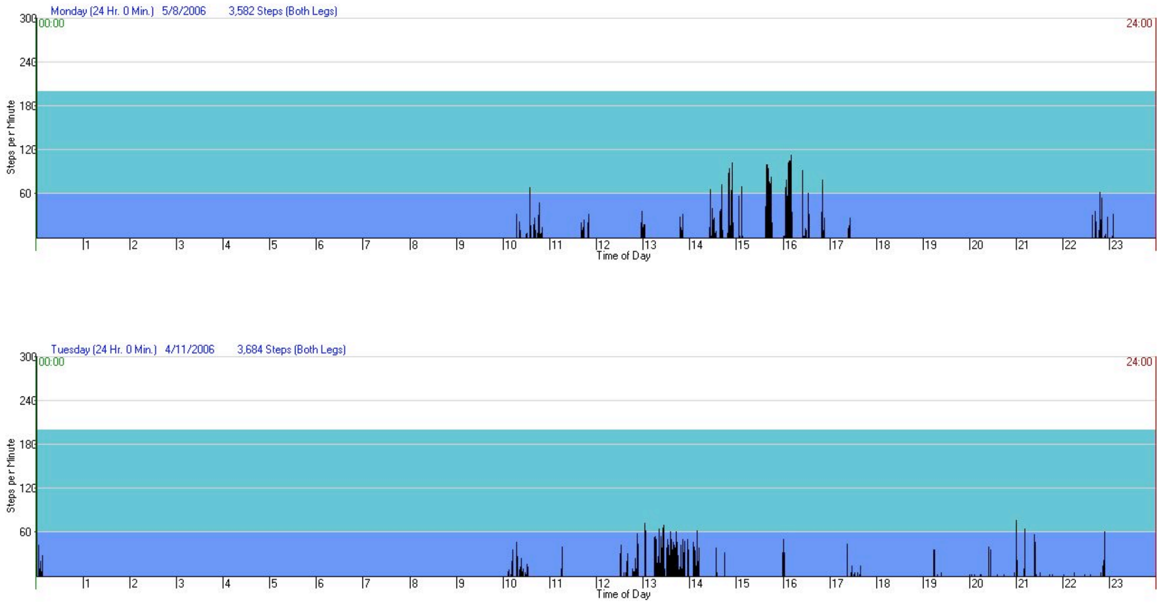
Figure Legend

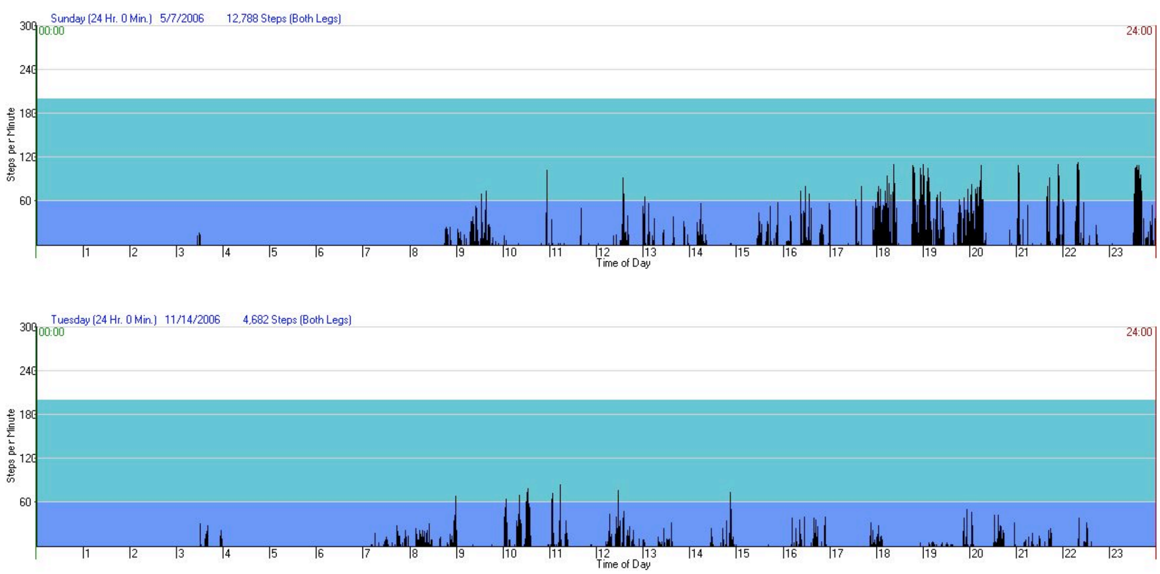
Twenty-four hour recordings of ambulatory activity from four study participants. Panel A: Participants display a similar amount of accumulated steps yet different complexity profiles. The lower activity recording reveals relatively more complex temporal structure than the upper recording. Panel B: Participants display dramatically different amounts of accumulated steps yet similar complexity profiles.

Figure 1

A


Monday (24 Hr. 0 Min.) 5/8/2006 3,582 Steps (Both Legs)
Tuesday (24 Hr. 0 Min.) 4/11/2006 3,684 Steps (Both Legs)
Steps per Minute
Time of Day
00:00
24:00

B


Sunday (24 Hr. 0 Min.) 5/7/2006 12,788 Steps (Both Legs)
Tuesday (24 Hr. 0 Min.) 11/14/2006 4,682 Steps (Both Legs)
Steps per Minute
Time of Day
00:00
24:00