Annals of Biomedical Engineering, Vol. 40, No. 12, December 2012 (© 2012) pp. 2505–2506
DOI: 10.1007/s10439-012-0586-4

Letter to the Editor: "Sensitivity of the Wolf's and Rosenstein's Algorithms to Evaluate Local Dynamic Stability from Small Gait Data Sets"

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(Received 27 December 2011; accepted 27 April 2012; published online 8 May 2012)

Associate Editor Catherine Disselhorst-Klug oversaw the review of this article.

In a recent study, Cignetti *et al*.[2] compared the use of Rosenstein's,[5] and Wolf's[7] algorithms to evaluate dynamic stability of gait. Properly assessing stability of gait may be of great benefit but is fraught with difficulties, especially when using short datasets, rendering such a comparison important. Nonetheless we would like to express some concerns about validity of methods and interpretation of results in that study.

Cignetti *et al*. estimated Lyapunov exponents for the seminal Lorenz system and subsequently compared Lyapunov exponents of young and old subjects while walking. For the latter the duration of experimental trials was fixed to 3 min. By fixing trial duration, however, the number of stride cycles may have differed between groups because younger subjects walked faster. The fact that the speed difference between groups was not significant does not exclude speed as confounder, as the authors erroneously state. Moreover, stride times have not been reported but might have been shorter for young subjects. Shortening stride times could have resulted in larger Lyapunov exponents, since more stride cycles were included in the analysis of the younger subjects.[1,3] Hence, in Cignetti *et al*.'s study, group differences may be biased due to differences in speed and stride times.

Cignetti *et al*. rescaled time in the divergence curve used in Rosenstein's algorithm. While this is a valid method that avoids potential pitfalls of resampling a time series, it potentially creates a bias when comparing to Wolf's algorithm. To explain, in Wolf's algorithm time is not rescaled so that there the rate of exponential divergence is conveyed per unit of time, whereas Rosenstein's algorithm expresses the rate of exponential divergence per gait cycle. Furthermore, for Wolf's algorithm, potential differences in stride times between groups likely increase the differences in Lyapunov exponents between groups. This problem could have been overcome by adjusting Eq. (3) to

$$\lambda_1 = \frac{1}{(t_M - t_0)/t_{\text{stride}}} \sum_{k=1}^{M} \ln \frac{L'(t_k)}{L(t_k - 1)}$$

in which all symbols agree with those in the original equation with the addition that t_{stride} is the average stride time.

These methodological choices may explain why some of Cignetti *et al*.'s results differ from those in earlier reports: For gait data, increasing signal length in Cignetti's analysis led to a drop in Lyapunov exponents, in particular λ_s whereas[1,3] reported increasing exponents with increasing signal length.

Finally, Cignetti *et al*. concluded that Wolf's algorithm is to be preferred over Rosenstein's based on its higher sensitivity to age. Indeed, Wolf's algorithm might be more sensitive to differences between groups

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(although this sensitivity may be spurious and biased by differences in stride times as outlined above), but it is also more sensitive to changes in embedding dimension and embedding lag.[2] Embedding dimension and time lag can only be estimated with limited precision and limited validity from short time series,[4,6] and given its higher sensitivity to dimension and time lag, errors in these estimates will have larger effects for Wolf's algorithm.

Taken together we consider it yet premature to conclude that either algorithm is superior, because (1) the results presented by Cignetti *et al*. may be subject to differences in stride time between the YA and OA, which could be the single cause of the age effect found by Wolf's algorithm, and because (2) Wolf's algorithm is more sensitive to the choice of embedding dimension and time lag, which are especially difficult to determine for small data sets.

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