Interpreting Dynamical Aspects of Movement Variability: Implications for Rehabilitation Providers

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Introduction
While we may have little knowledge of how nonlinear dynamical measurement procedures are informing rehabilitation practice, it is likely some of our faculty are exploring these concepts. A recent Medline search, for example, indicated the number of publications using the key words "nonlinear dynamics" OR "complexity" OR "fractals" AND "movement" has increased exponentially since William Ljunggren published the first paper using "nonlinear dynamics" and "movement" as key words in 1989 (Fig. 1).

In particular, examining nonlinear properties of movement variability (e.g., complexity and fractals) in the context of rehabilitation is emerging as a potentially more informative way to analyze movement tasks that require a complex interaction of body segments while examining traditional linear measurements of those tasks. The movement system is dynamical, one that exhibits fluctuating change over time or over repeated movements, as illustrated in Fig. 2. Linear analyses (mean and SD) may inadequately quantify the fluctuating nature of such signals.

Purpose
To describe how gait variability, analyzed via nonlinear methods, may inform our interpretation of walking capacity. We've examined effects of treadmill ambulation or of using ankle-foot orthoses (AFOs) on gait.

Methods
Participants
Healthy participants (n=20);
Participants with Parkinsonism (n=6);
Participants with hemiparesis following stroke (n=13);
Participants (n+1) with asymmetric lower extremity paresis associated with chronic inflammatory demyelinating polyradiculoneuropathy (CIDP).

Data Processing
- Completely across trial series data was quantified with sample entropy (SampEn) according to methods described by Richman & Moorman.1
- Self-similarity in trial series data were quantified with H (Hurst) exponents via adaptive fractal analysis according to methods described by Richman & Moorman.1
- H = 0.5 - random process, data points uncorrelated.
- H = 0.5-1.0 - persistently correlated process, increases in signal more likely followed by further increases.
- H > 0.5 - anti-persistent process, increases in signal more likely to be followed by subsequent decreases.

Statistical Analyses
- Linear estimates (means & SDs) were calculated for each gait parameter (stride length and stride time).
- SampEn and H exponents calculated for each gait parameter.
- Where appropriate, dependent t-tests (t<0.05) were used to compare data between walking conditions (i.e., overground vs treadmill; without AFO vs with AFO).

Results
Treadmill Effects
- In healthy participants (Fig. 4), mean stride times were equivalent in overground (1.03±0.05 s) and treadmill (1.03±0.05 s) conditions (p>0.20), but stride time signals were less complex (overground SampEn 2.0±0.15, treadmill SampEn 1.85±0.21) and less self-similar (overground H exponent 1.85±0.20, treadmill H exponent 1.87±0.33) on the treadmill.
- Stride signals in participants with Parkinsonism (Fig. 5), however, were less complex in comparison SampEn 1.89±2.0, treadmill SampEn 1.87±2.30) and in fractal self-similarly (overground H exponent 0.81±0.09, treadmill H exponent 0.73±0.09). Mean stride times were also equivalent (1.10±0.14 m/s and 0.83±0.14 m/s) on the treadmill with reduced stride lengths (1.14±0.08 s vs 1.01±0.09 s).

AFO Effects
- In select individuals with asymmetric lower extremity paresis (Fig. 6), sample entropy (e.g. 1.80±2.526, respectively) and fractal H exponents (e.g. 0.73 and 0.71, respectively) increased when walking with the AFO.

Discussion & Conclusion
Reduced complexity characterizes biological systems that are rigid, unchanging and predictable.2 Similarly, fractal H exponents that approach 0.5 reflect a random, simplistic physiologic system.3 Increases in complexity and fractal exponents reflect more complex, adaptable, healthy dynamical systems.

In persons with asymmetric lower extremity paresis, our findings provide some evidence that using an AFO may produce gait signals representing that of a more complex, adaptable and healthy dynamical system. Interpreting nonlinear gait dynamics may provide more insight about one's walking capacity than is provided through traditional linear measurements of gait parameters.

References