THE EFFECT OF SPEED ON PERFORMER VARIABILITY DURING LOCOMOTION

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INTRODUCTION

Slower speeds have shown to lead to increased variability during walking (Winter, 1983). That was also found to be true with neuropathic patients (Dingwell et al., 2000). However, Dynamical Systems Theory (DST) predicts that the least amount of variability (a highly stable state) will be present at a self-selected pace. When the system is perturbed, then variability increases. Based on DST, variability in locomotion can then be modeled as a parabola. This model has also been supported by energy expenditure data. Furthermore, the examination of variability has been traditionally conducted using standard deviations across multiple strides. However, such an approach implies that locomotion is a sequence of independent strides. Tools for analyzing nonlinear time series have been shown to provide a more detailed analysis and can possibly reveal information about underlying control mechanisms (Dingwell et al., 2000; Stergiou et al., 2000). The purpose of this study was to investigate the effect of speed on variability during two different modes of locomotion, walking and running. We examined biomechanical parameters using tools of mathematical chaos.

PROCEDURES

Twenty subjects (range: 19-35 yr) attended 5 test sessions on 5 different days. On the first day, the subjects walked on a treadmill to establish a comfortable self-selected pace. This pace was used as the baseline speed for subsequent testing. Following this procedure, the subjects were required to walk for 5 minutes at 5 different speeds: baseline, 10% and 20% faster, and 10% and 20% slower. The same procedure was used for running. The subjects completed one walking and one running condition each day. The order of presentation of the conditions was randomized. A quartz shear piezoelectric accelerometer (PCB Piezotronics) was attached to subjects' distal anteromedial aspect of the right tibia with a tight elastic wrap. The time series from the accelerometer data sampled (180 Hz) were analyzed using the Chaos Data Analyzer software (Sprott, 1992). The Lyapunov Exponents (LE) and the Correlation Dimensions (COD) were calculated. LE is a measure of the stability of a dynamical system and its dependence on initial conditions. COD describes the geometric dimension of a dynamical system. All calculations were performed using five embedded dimensions. The embedded dimension, a description of the number of dimensions needed to unfold the structure of a given dynamical system, was calculated from a Global False Nearest Neighbor (GFNN) analysis (Abarbanel, 1996). Mean group values for LE and COD were analyzed statistically using one-way repeated measures ANOVAs ($p<0.05$).

RESULTS AND DISCUSSION

The average baseline speeds were 1.35 $m\bullet s^{-1}$ and 2.45 $m\bullet s^{-1}$ for walking and running, respectively. All LyE results were positive (Table 1), which may indicate that the system is behaving chaotically. However, a time series consisting of random or noisy data can also produce positive LE. Thus, to assist in our evaluations we processed time series from periodic data (sine wave), from randomly generated data, and from known chaotic data (Lorenz attractor). When these data are compared with our LyE results, we can see that our results are more chaotic than noisy. It is also evident that both LyE and COD significantly decreased with increases in running speed. This may indicate a change in variability, which can be interpreted as an increase in periodicity and less control with larger speeds. No significant differences were observed for LyE during walking. The COD values were significant and actually, the 20% slower speed had the larger COD value. This result partially supports previous findings that indicated increased variability with slower speeds. Random data also have high COD in comparison with chaotic or periodic. Thus, it is possible that this increased variability is the result of higher noise within the system.

SUMMARY

The time series collected from a tibia located accelerometer were analyzed with tools of mathematical chaos. Our results did not confirm the DST parabolic model of variability for both walking and running, since the self-selected speed did not have the smaller value for either LyE or COD. In fact, the results revealed a linear relationship between variability and speed during running. The methods used in this study can assist in understanding the control mechanisms in complicated nonlinear systems such as the human.

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Table 1: Chaotic parameters evaluated for both modes of locomotion (group means). Significant means ($p < 0.05$) are identified with superscripts.

	20%Slower	10%Slower	Self-Selected	10%Faster	20%Faster
WALK - LyE	0.164	0.158	1.161	0.167	0.156
WALK – COD	4.121[10%S, 20%F]	3.769[10%F]	3.935	4.065	3.899
RUN - LyE	0.154[20%F, 10%F, SS]	0.135	0.128	0.125	0.114
RUN - COD	3.548[20%F, 10%F, SS]	3.339[20%F]	3.245	3.239	3.139

	PERIODIC	CHAOTIC	RANDOM
LyE	-0.001 ± 0.032	0.100 ± 0.035	0.469 ± 0.037
COD	1.167 ± 0.334	1.941 ± 0.110	4.723 ± 0.723