DOES GRAVITY INFLUENCE THE STRUCTURE OF CHAOTIC GAIT PATTERNS?

[1]Max J. Kurz, [1]Nicholas Stergiou, [2]Jacob Bloomberg and [1]David Miller
[1]HPER Biomechanics Laboratory, University of Nebraska at Omaha, Omaha, NE
[2] Neuroscience Laboratory, NASA-Johnson Space Center, Houston, TX
E-mail: mkurz@mail.unomaha.edu Web: http://www.unocoe.unomaha.edu/hper/bio/home.htm

INTRODUCTION

Historically, fluctuations in human gait patterns were considered to be random noise or error in the output of the nervous system. However, recent investigations have suggested the contrary and have indicated that such fluctuations have a chaotic structure. A chaotic structure means that the lower extremity kinematics fluctuate from one step to the next with a deterministic pattern. Changes in the chaotic structure appear to be related to the health and stability of the neuromuscular system [1].

The Lyapunov exponent (LyE) is used to quantify the chaotic structure present in a gait pattern [1]. The LyE for a periodic signal (e.g. sine wave) is zero, which indicates no separation in the attractor's trajectory. Alternatively, the LyE for Gaussian noise is positive (+0.469) and indicates divergence in the attractor's trajectory. Hence, a time series that has LyE value close to +0.469 indicates instability, while a time series with LyE close to zero indicates stability or possibly rigidity. The chaotic structure of human locomotion lies somewhere between these two extremes [1]. The degree of stability of a gait pattern can be explored from a chaotic perspective by investigating whether the LyE value shifts towards one of the two extremes, as the independent variable is scaled.

The influence of Newtonian forces on gait stability is not yet completely understood. Here we explore the influence of gravity on chaotic gait stability with a passive dynamic bipedal walking model and experiments where humans walk at simulated micro-gravities.

METHODS

The passive dynamic bipedal model consisted of two rigid legs connected by a frictionless hinge at the hip (Figure 1; [2, 3]). Slight increases in the ramp angle of the walking surface promote a cascade of bifurcations that lead to a chaotic gait pattern [2, 3]. Different micro-gravities were simulated by decreasing gravity in the model's governing equations at the respective ramp angles. A custom built body weight suspension (BWS) system was used to experimentally explore the influence of various micro-gravities on human chaotic locomotion. The BWS supplied a constant upward force on the subject's center of gravity via a cable-spring-winch system that was monitored with a force transducer [4]. Five subjects walked on a treadmill for two minutes under the following micro-gravities: 1.0, 0.9, 0.8, and 0.7 Gs. LyE values were calculated for the sagittal plane joint angle time series of the hip, knee and ankle with an embedding dimension of five.

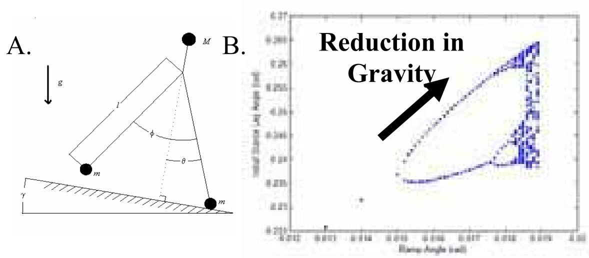

Figure 1. The passive dynamic walking model (A). Bifurcation map of the model's locomotive patterns for the respective ramp angles. Chaotic gait exists when ramp angle is greater than 0.1839 radians [3] (B).

RESULTS AND DISCUSSION

Our simulations provided initial evidence that gravity influences the structure of chaotic gait patterns. As gravity was reduced the model's gait bifurcated towards a chaotic gait pattern that was closer to instability (Figure 1B). The human experiments complemented our model's simulations (Table 1). In general, as gravity was reduced the human chaotic gait patterns shifted towards instability. A significantly increasing linear trend was found for the ankle joint ($p = 0.03$) where lower micro-gravities were associated with less stability. Hence, changes in gravitational forces influenced the performance of the ankle for maintaining stable gait patterns. Although a reduction in gravity is associated with a more economical gait [4], our results indicate that it is not associated with a more stable gait. Alternative counter measures for maintaining a stable gait in micro-gravity environments (i.e. the Moon or Mars) may be necessary. Our future investigations will reveal how changes in other Newtonian forces influence chaotic gait patterns.

REFERENCES

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Table 1. LyE means and standard deviations for the respective lower extremity joints and micro-gravities.

Joint	1G	0.9G	0.8G	0.7G
Ankle	0.176 (.03)	0.189 (.02)	0.196 (.02)	0.213 (.02)
Knee	0.104 (.05)	0.120 (.04)	0.120 (.04)	0.124 (.03)
Hip	0.109 (.03)	0.107 (.02)	0.117 (.02)	0.119 (.01)