**Efficient Variability: Linking Fractal Walking Patterns with Metabolic Energy Savings**

**Project Description**

Decades of research in biomechanics, neuroscience, and biology have produced two theories on why humans select certain movement strategies: 1) humans move in a way that minimizes metabolic energy cost and 2) cyclical movement strategies tend toward fractal patterns (i.e. the variability in each movement is neither random nor fixed). While these theories are seemingly independent, the primary objective of this research is to investigate the relationship between metabolic cost and fractal stride patterns in human walking. This research will lead to a unified understanding of human movement strategies, which will provide the groundwork for new discoveries in human movement research and the development of rehabilitation and diagnostic techniques.

**Saving Energy** Humans prefer a movement strategy that is most energy efficient. As a person deviates from his/her preferred movement strategy, metabolic cost increases. For example, higher stride frequencies cause more frequent muscle activation, increasing the metabolic cost. Lower stride frequencies require longer steps to be taken, resulting in higher mechanical requirements for the leg muscles. Other factors, such as speed and step width, have similar effects.

**Fractal Nature** Any event series can be measured for persistence. Persistence is used in this context to describe how similar an event is to the events that precede it. For example, white noise has very low persistence (i.e. random) and a sinusoidal wave has very high persistence (Fig. 1). When applied to human walking, we find that changes in gait characteristics (such as stride length, time, and speed) tend toward a fractal pattern: a pattern that is neither random nor perfectly persistent. As a person deviates from his/her preferred walking speed (PWS), an increase in persistence is observed, indicating a preference for a less persistent and near fractal movement pattern.

**Efficient Variability** Separate studies have observed that as a person deviates from the PWS, increases are observed in both metabolic cost and in gait pattern persistence, indicating a potential relationship between these two factors. Further evidence for this relationship can be deduced from pathologies. For example, increases in metabolic cost and in gait pattern persistence have been observed in lower-limb prosthesis users and in patients with peripheral arterial disease. I propose a central hypothesis that a person’s gait pattern persistence is directly related to metabolic cost, such that changes in this persistence can drive changes in metabolic cost.

This hypothesis will be tested using two experiments: First, I will determine the relationship between metabolic cost and gait pattern persistence as individuals walk across a series of different speeds; Second, I will determine a more robust relationship by manipulating gait pattern persistence, and measuring its effect on metabolic cost.

**Methodology**

**Recruitment** Previous studies investigating gait pattern persistence and metabolic cost of transport have recruited 10-20 healthy, young participants. Following this example, the current study will aim to recruit 25 healthy participants, ranging in age from 19 to 35 years. Participants
will be eligible for inclusion if they do not present with conditions affecting gait (i.e. recent lower limb injury/surgery, visible gait abnormalities, cardiac or neurological problems, etc.)

**Aim 1**: To determine the relationship between metabolic cost of transport and gait pattern persistence at different walking speeds.

25 subjects will walk on a treadmill at five speeds ranging from 0.75 – 1.75 ms\(^{-1}\), as well as a self-selected preferred walking speed (PWS). Indirect calorimetry will be used to measure metabolic cost of transport, which is a measure of the amount of energy required to traverse a given distance. Gait pattern persistence will be calculated by detrended fluctuation analysis (DFA) of the stride length, time, and speed, determined by a motion capture system\(^2\) that tracks retroreflective markers placed on the participant. PWS will be determined by increasing and decreasing treadmill speed until a comfortable speed is found\(^9\). A Pearson’s correlation coefficient will provide information on the relationship between gait pattern persistence and metabolic cost, and a repeated measures, one-way ANOVA will be used to compare values between speed conditions.

**Hypothesis 1**: Metabolic cost and gait pattern persistence will be positively correlated, and both will be minimized near PWS (Fig. 2).

**Aim 2**: To determine the effects of fractal gait pattern manipulation on metabolic cost of transport during walking.

25 subjects will walk on a treadmill at PWS while facing a display screen. For the first trial, the screen will be blank and the participant will walk while measurements are taken to determine his/her native gait pattern persistence and step width. During all other trials, the display screen will present a target step width for each step, and the participant will be instructed to match the step width presented. The target width will change each step according to a pre-programmed pattern, and maintain the same range and average values as observed in the first trial. Five patterns, ranging from random to highly persistent, will be used to conduct five trials. Indirect calorimetry will be used to measure metabolic cost of transport, and DFA will be used to measure gait pattern persistence. A one factor, repeated measures ANOVA will be used to examine the effects of persistence manipulations on metabolic cost.

**Hypothesis 2**: Metabolic cost will be minimized at the level of persistence most similar to the persistence observed during normal walking (Fig. 3).

This study embraces the ideas upon which UNO’s Center for Research in Human Movement Variability was founded. This facility is uniquely equipped with technologies specific for investigations in to movement variability, metabolic cost, and other similar inquiries.
Conceptual Importance  This research will bridge two prevailing theories on why humans move the way they do (metabolic cost and fractal gait patterns), and will provide a basis on which to make new discoveries about why humans select a specific movement strategy. The more we learn about the benefits of certain human movement strategies, the closer we will come to understanding the underlying mechanisms that govern human movement, such as muscle action, innervation, and central nervous system activity.

A previous study has shown that variability in step width during walking has an effect on metabolic cost. My proposed research aims to answer whether changes in the pattern of this variability have an effect on metabolic cost. My anticipated results will establish gait pattern persistence as a potential determinant of metabolic cost, leading to a more complete understanding of the energetic cost of walking.

Contribution to Student's Graduate Studies  This study will further expose me to various methodologies used in biomechanical analysis, providing me with experience in: retroreflective marker placement, motion capture and analysis software, and indirect calorimetry. I will also gain valuable experience in participant interaction, project leadership, and manuscript preparation. This study will provide me with a well-rounded scientific experience, in addition to taking the first step in establishing myself in the scientific community via publications.

Project Timeline

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<th>Month</th>
<th>2016</th>
<th>2017</th>
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<tr>
<td>IRB Preparation</td>
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<td>Recruit and Collect</td>
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<td>Aim 1</td>
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<td>Data Analysis</td>
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<td>Manuscript Preparation</td>
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<td>Presentation at RCAF</td>
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Roles of Student and Faculty Mentor

The student researcher will -

- Prepare and submit the IRB application, and address any review comments
- Recruit participants and lead data collections for Aim 1 and Aim 2
- Lead data analysis and processing
- Prepare a thesis
- Prepare manuscripts to be submitted to peer-reviewed journals, such as the Journal of Biomechanics, Journal of Experimental Biology, Journal of Applied Physiology, etc.

The faculty mentor will -

- Review IRB materials
- Supervise and advise on data collection
- Review thesis and manuscript
**Budget Justification**

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<tr>
<td>Participant Stipend</td>
<td>$1000.00 ($20 per participant)</td>
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<tr>
<td>Visual 3D Student License</td>
<td>$750.00</td>
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<tr>
<td>Student Stipend</td>
<td>$3,250.00</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>$5,000.00</strong></td>
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I request a total of $5,000.00 for the completion of this research project. As the research will take place in the Biomechanics Research Building, a large majority of the required equipment to conduct this research is available. However, an addition Visual3D student license would help to speed data processing. Currently, licenses are shared between students, limiting the productivity by only allowing one person to use the software at a time. More licenses would allow me to complete data analysis unhindered. The participant stipend will be provided to the participants upon completion of the experimental protocol, and will assist in expediting recruitment of participants. Lastly, a student stipend will provide me the funds to spend more time at the Biomechanics Research Building to collect and analyze data.
References
5. Wuehr, M; Pradhan, C; Brandt, T; Jahn, K; Schniepp, R. *Gait & Posture*, 2014
7. Kent, JA; Stergiou, N; Wurdeman, SR. *Clinical Biomechanics*, 2015.
9. Myers, SA; Johanning, JM; Stergiou, N; Celis, RI; Robinson, L; Pipinos, II. *Journal of Vascular Surgery*, 2009
January 18, 2016

Dear GRACA Grant Reviewers:

It is with the **highest level of enthusiasm** that I write this letter of recommendation for Mr. Chase Rock. I have known Chase for three months, ever since he began his MS in Exercise Science (with a concentration in Biomechanics). He has joined my research team in the Biomechanics Research Building at the University of Nebraska Omaha (UNO). In the short time that I have known him, Chase has established a very strong reputation as a diligent worker and a promising young scientist.

I first met Chase in summer 2015, immediately before he was beginning his graduate curriculum. In our first meeting, he expressed great interest in conducting biomechanics research to help people with prosthetic limbs. This interest stemmed from his days of volunteering at the Biomechanics Research Building during his undergrad. He gained valuable experience working with Dr. Shane Wurdeman, a certified prosthetist performing ground-breaking research. Because of this experience, Chase is very advanced with his overall knowledge and his awareness of how his research could be translated into clinical practice. I was particularly impressed with his ability to articulate his career goals and his efforts to merge his undergraduate Neuroscience training with his graduate education in Biomechanics. Historically, there has been a disconnect between the fields of Neuroscience and Biomechanics. Chase is ideally suited to tackle this challenge, and his research proposal is a very fine example of his inter-disciplinary approach.

In the last few months, Chase has worked very diligently to formulate his research plan. To be honest, I offered very little supervision on his research ideas and he has shown great capacity to work independently. This is extremely rare given his career stage. His research merges two distinct theories related to human locomotion: 1) humans move in a way that minimizes metabolic energy expenditure, and 2) humans move with a certain variability structure that resembles a fractal pattern. Chase’s work is important because these two theories have traditionally been studied in isolation, and his work will identify the potential link to bridge the gap. This work also harnesses the strength of UNO Biomechanics program, in particular the Center for Research in Human Movement Variability.

In summary, Chase is intelligent, diligent, and has exceptional work ethic. He is very well-positioned to have a successful career as a biomedical scientist. If you have any questions regarding his qualifications, please contact me via phone (734-649-3397) or via email (ktakahashi@unomaha.edu).

Sincerely,

Kota Takahashi, Ph.D.