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<u>Note:</u> *I would like to be considered for a student travel grant.*

<u>Title:</u> Humans exploit the biomechanics of bipedal gait during visually guided walking over rough terrain.
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<u>Keywords:</u> Vision, rough terrain, human walking
<u>Preferred Format:</u> Talk

<u>Motivation:</u> Just as gymnasts harness the linear and rotational inertia of their bodies to execute a complicated floor routine, humans capitalize on the physical forces inherent to a moving body in order to walk with extraordinary levels of efficiency. When walking over complex rough terrain, such as a rocky trail, people must choose footholds on the basis of visual information that will allow them to approximate the level of efficiency realized during obstacle-free steady state walking.

Our research investigates the relationship between the biomechanics and visual control of human walking. In particular, the aim is to understand the way in which humans capitalize on the basic mechanical structure of bipedal walking when selecting footholds on the basis of visual information during walking over rough terrain. By combining the rich theoretical framework developed by researchers in biomechanics and robotics with the careful experimental protocols utilized in research on the visual control of movement, our study provides new insights into the control of locomotion that we believe will be of interest to gait researchers from all fields.

<u>State of the Art:</u> This research project brings together two fields that presently have little cross over – vision science and biomechanics. Typically, researchers studying the visual control of human walking overlook the biomechanics of gait, focusing instead on descriptive measurements (such as step length, joint angles, toe clearance, etc) as the dependent measures in behavioral experiments. Similarly, research on the biomechanics of gait tends to sideline questions related to the visual control of walking by focusing on steady state walking over flat terrain[1].

Although researchers from these two disciplines have enjoyed some success by working in isolation, I believe that a multi-disciplinary perspective that integrates these fields could yield greater success and foster a transformative shift in the study of human walking and legged robotics. The current project seeks to foster such intellectual collaboration by applying the tools and theoretical framework provided by the dynamic walking biomechanical model of human gait to study the visual control of walking over rough terrain.

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[1] However, I was happy to see that the main description of the Dynamic Walking meeting no longer explicitly states a de-emphasis on vision, as it has in past years.

<u>My Approach:</u> For this study, we performed a behavioral experiment using a paradigm in which subjects walked over an array of randomly distributed virtual obstacles that were projected onto the floor by a LCD projector while their movements were recorded using a full-body motion capture system. Subjects' walking behavior was analyzed during a full-vision control condition as well as in a number of other visibility conditions wherein obstacles were only visible when they fell within a window of visibility centered on the subject. A brief video demonstration of this experimental set up is available here: http://bit.ly/qnBErw.

During the single-support phase of the gait cycle, a walker is structurally similar to an inverted pendulum. As such, in the absence of muscular intervention, the passive mechanical structure of bipedal walking should carry the walker's center of mass along a trajectory similar to that of an unactuated 3D inverted pendulum. The dynamic walking model of bipedal gait suggests that humans achieve high levels of walking efficiency in part by capitalizing on the energetically lossless movement of this inverted pendulum structure.

In order to test whether visual information is used to choose footholds that exploit the passive mechanical structure of bipedal gait, we compared the trajectory of subjects' COM during each step to the predicted trajectory of an idealized 3D inverted pendulum. As predicted, the difference between subjects' COM trajectory and the predicted trajectory of an idealized inverted pendulum varied with the size of the visibility window. Large deviations occurred when visual information was constrained to less than two steps ahead, with performance returning to levels similar to the full vision condition when subjects could see more than two steplengths ahead. The dynamic walking model provides a useful framework for interpreting these findings. When humans walk over rough terrain, two steplengths of visual information about the upcoming path provides all of the information necessary to fully exploit the passive mechanical structure of bipedal gait. As such, two steplengths of visibility is sufficient to identify footholds that allow them to better approximate the efficiency of walking over flat, uncluttered terrain.

<u>Discussion Outline:</u> The results of this study provide strong evidence that humans use visual information about their upcoming path to choose footholds that allow them to maximally exploit the passive mechanical forces inherent to bipedal walking in order to walk efficiently over rough terrain. As such, this study provides some insight into what may be a primary function of vision in the control of locomotion. Discussion questions related to this project abound, including:

- What is the nature of the visual information that guides foot placement?
- What implication does this finding have for the development of visual control systems for legged robots?
- How would the analysis change if a more sophisticated biomechanical model were used in place of an unactuated, point-mass, fixed-length pendulum?
- How could the pendulum comparison analysis developed for this project benefit the clinical assessment of gait disorders, gerontology, rehabilitation and prosthetic research?