Characterizing human leg force control

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Summary
For humans or robots to jump high, run fast, and rapidly change direction, they must be able to selectively modulate the magnitude and position of the external forces they apply to the world. Our purpose here is to quantify the voluntary control performance of human leg force-magnitude and force-position control. To accomplish this, we are building a rig that constraints upper body motion while allowing for the leg to selectively push against a force plate. We present subjects with the force-magnitudes and force-positions that they are exerting on to the ground and ask them to match a prescribed step function. We use system identification to characterize the control performance of the leg and find response times of ~0.45-1.2s, steady state error of ~0.5-14.5%, and steady state variability of ~2.4-21.2%. While preliminary, the leg's voluntary control of force seems remarkably poor in the context of the superior agility of humans.

Introduction
Humans are remarkably agile. We think of agility as the ability to rapidly execute motor control strategies that redirect body motion and reposition our limbs. When we navigate the environment, our legs interact with the ground producing reaction forces that either maintain or change the state of our motion. Each reaction force is a vector quantity with a force-magnitude acting at a point on the body, which we refer to as its force-position. Alteration in the force-magnitude of the force can result in linear changes to our motion. A runner who wishes to increase their linear speed, does so by increasing the force-magnitude. Alteration in the force-position results in changes in the moment of the force, which has rotational effects on our motion. A gymnast wishing to initiate a front flip does so by selectively shifting the force-position. A greater control of agile motion is achieved through greater control of leg reaction force-magnitude and force-position – modulating force rapidly and accurately contributes to greater agility. If we seek to design robots that exceed the agility of humans, it helps to understand the neuromechanical control mechanisms that enable agility as well as the factors that limit it. The goal of our research is to quantify the control performance (response time, steady state error and steady state variability) of humans using their legs to voluntarily control the force-magnitude and force-position of external forces.

Methods
To study the performance of our legs controlling force-magnitudes and force-positions, we are designing an apparatus that situates subjects into an upright posture above a force plate with their upper body constrained in all directions (Fig. 1). We send signals from the force plate to a data acquisition unit programmed in MATLAB to display to subjects' real-time feedback on the vertical force-magnitude and of the medial-lateral and anterior-posterior force-position of the external force being applied to the ground. We focus on sub-maximal forces to study the limits to control, not the limits to maximum force generation which can also affect agility [1]. We focus on a single leg as individual leg control is important in agile motion.

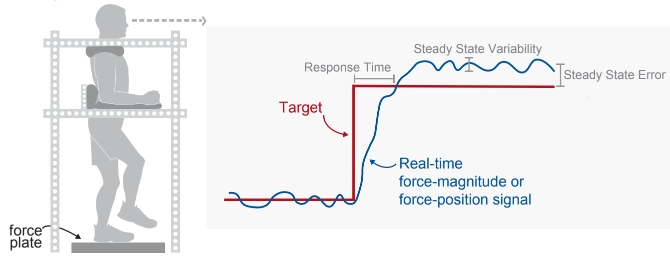

Figure 1: Experimental set-up constraints the subject and presents them with real-time external force-magnitude and force-position.

In our current pilot experiments, we use prescribed step functions to characterize the voluntary control of force-magnitudes and force-positions. For force-magnitude control, subjects use their leg to selectively try and match the magnitude of a prescribed force by pushing or not pushing against the ground. For force-position control, subjects place their foot firmly at the center of the force plate and try to match a prescribed change in the medial-lateral and anterior-posterior force-position. We performed each condition 8 times on one subject. We compare the prescribed signal to empirical data and quantify control performance criteria which includes: response time, steady state error and steady state variability using system identification tools in MATLAB.

Results and Discussion
Preliminary results are shown below (Fig. 2). Control performance variables **(**response time, steady state error and steady state variability) found for force-magnitude are 1.18s, 0.5% and 2.4% respectively. For force-position in the medial/lateral direction, the performance variables found are 0.5s, 14.5%, and 21.2% respectively and for the anterior/posterior direction they are 0.45s, 7.1% and 12.0%.

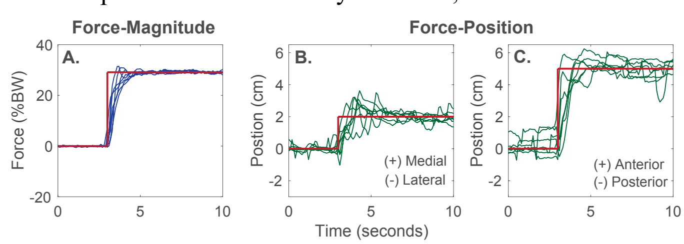

Figure 2: Force-magnitude (A) and force-position (B, C) control.

One limitation here is that we have not accounted for motor learning. As we move forward and fine tune our methods, our aim is to determine the amount and type of exposure subjects require to maximize performance. To do this, we are reviewing literature on motor learning where the experiments require subjects to perform a repetitive task maximally.

Acknowledgments
NSERC PGS-D (P.K.) and NSERC discovery grant (M.D.)

References
[1] K. P. Clark, L. J. Ryan, and P. G. Weyand, *J. Exp. Biol.*, vol. 220, no. 2, pp. 247–258, 2017.