The Hypothesis of Feedback Pattern Generation in Human Locomotion

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1 Motivation

Human locomotion is a complex task involving energy-efficient control of rhythmic patterns. One theory of human locomotor control proposes that reflexive feedback mechanisms generate rhythmic motions [1]. The prevailing theory, central pattern generation (CPG), instead proposes that spinal centers act as internal timers to produce patterns of muscle activation that repeat periodically over time [2]. These two schools of thought could possibly be unified by a hypothesis recently used to control walking and running in bipedal robots as a function of a mechanical representation of phase, i.e., a phase variable [3].

2 State of the Art

Imagine walking along a riverbed and stepping on a rock that slips beneath your heel. This unexpected change in the ground slope rotates your foot towards your shank, i.e., dorsiflexes your ankle. Your ankle would normally encounter the dorsiflexed position later in the gait, so the most economical response might be to continue from the later position and follow the remaining portion of the normal pattern, i.e., a shift in phase. If controlled by an internal clock that advanced at a fixed rate, your ankle pattern would maintain the same timing after the perturbation, i.e., no change in phase. Feedback reflex mechanisms could possibly respond to the new state of the ankle [1], but some explicit measure of phase would be necessary for a phase shift. Recent robots such as MABEL would experience this phase shift because their joint patterns are controlled as functions of a mechanical phase variable [3], which begs the question as to whether humans employ such a variable in locomotor control.

3 Own Approach

Given substantial evidence that phase-specific behaviors in human locomotion are initiated by ankle-foot loading [4], we postulate that the human spinal centers associated with CPGs use state-dependent feedback, specifically the Center of Pressure (COP), as a continuous representation of phase. If human locomotion depends on the heel-to-toe movement of the COP, your neuromuscular system would sense a shift in this phase variable caused by a slope change and your ankle would respond according to the new phase location. We experimentally tested this hypothesis with 13 able-bodied subjects, who walked over a robotic platform that unexpectedly rotated the ground slope beneath the stance foot (see supplemental video [5]). We employed a novel method of gait analysis, wherein trials are averaged across COP samples rather than time samples to preserve meaningful phase-dependent variability.

4 Current Results

We found that after the ankle is unexpectedly rotated to a position it would have later encountered in the step, the ankle continues the normal pattern from this later position (Figure 1). This statistically significant phase shift may suggest a novel theory of human locomotor control, which we term *feedback pattern generation* (FPG).

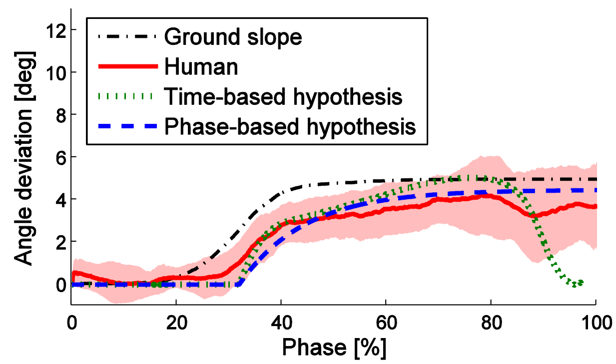

Figure 1. Deviation of ankle angle from unperturbed condition after 5-degree perturbation, shown as a function of the phase variable. Note convergence to shifted ground slope in phase.

5 Best Possible Outcome

The FPG hypothesis unifies two theories of human locomotor control, reflexive feedback mechanisms and CPGs, and suggests that humans walk much like recent robots. The COP appears to be a good phase representation and could be particularly useful in gait studies by providing an observable variable that uniquely represents phase after perturbations. These results also suggest that the COP can serve as an active sense of phase for controlling a prosthetic leg, which could improve robustness to perturbations.

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References

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