# PERTURBATION DIRECTION REVERSES THE EFFECT OF TIMING ON PEAK CENTER OF MASS SPEED

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## Introduction

Agile bipedal locomotion is crucial for humans to navigate the terrains and environments in daily life. However, we know relatively little about how individuals maintain balance in diverse environments, which would enable us to better treat populations with balance impairments and develop devices that augment balance. Previous work has employed perturbations to induce instability and study balance recovery [1]. However, no study has simultaneously evaluated the effects of perturbation *magnitude*, *direction*, and *timing* on balance, which would provide broad insight into the diversity of destabilizing scenarios that humans face during locomotion. Here, we investigate the combined effects of mediolateral (ML) perturbation direction and timing on balance, evaluated using peak ML center of mass (COM) speed. We hypothesize that perturbations beginning earlier in stance phase (*i.e.* longest time until next heel contact) will be followed by the largest peak ML COM speeds regardless of perturbation direction.

## Methods

One healthy participant walked at 1.25 m/s on a treadmill mounted on a Stewart platform. We applied 96 translational perturbation conditions that varied in magnitude (5, 10, 15 cm), direction (mediolateral, anteroposterior, diagonals), and timing (50% double stance, 25, 50, 75% single stance, Fig. 1B). Gait events were calculated according to [2]. The participant walked in three consecutive sessions, with each session containing one perturbation per condition, for a total of 288 perturbations.

We determined ML COM velocity as the average of four pelvis markers. Peak ML COM speed was determined as the peak absolute velocity in all recorded steps after the initiation of the perturbation. Perturbations were binned into two categories; lateral perturbations resulted in COM movement to the medial side of the stance foot and widened step widths, while medial perturbations resulted in COM movement to the lateral side of the stance foot and narrowed step widths.

## Results and Discussion

We evaluated linear relationships for both lateral and medial perturbations, including all perturbation magnitudes and all directions that had a mediolateral component (Fig. 1A). For lateral perturbations, we found a negative linear relationship between onset timing and peak ML COM speed ($p<0.001$). For medial perturbations, we found a positive linear relationship between onset timing and peak ML COM speed ($p<0.001$). The results indicate that timing has a significant effect on peak ML COM speed, but the effect is reversed by the perturbation direction (Fig. 1C). This indicates that double stance onset time is the most destabilizing for lateral perturbations, while late single stance onset time is the most destabilizing for medial perturbations.

## Significance

These results begin to provide a more thorough understanding of how multiple variables interact to influence balance. The outcomes across *magnitude*, *direction*, and *timing* in healthy individuals will provide a reference to understand the limitations of those with balance impairments. Additionally, these data provide guidelines for the design of intelligent wearable robots that seek to augment human stability and reduce fall risk. Future work will extend this analysis to stability in *all* directions and use whole body angular momentum to more thoroughly quantify balance recovery.

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## References

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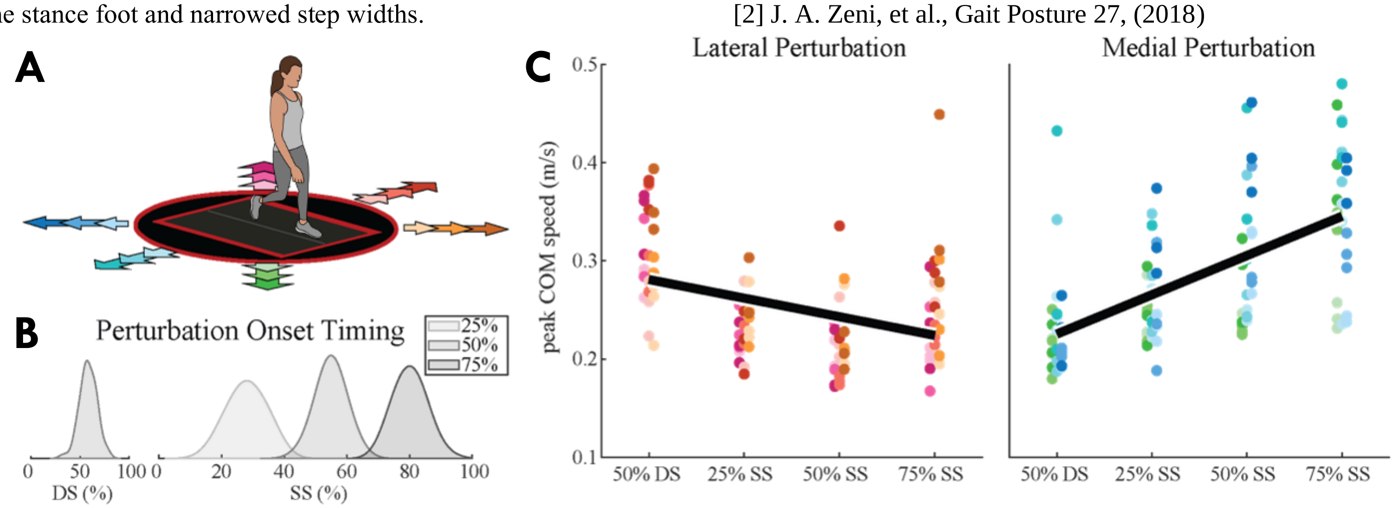


**Figure 1**: (A) Lateral (pink, red, orange) and medial (green, teal, blue) perturbations are shown. (B) The actual onset time distribution is plotted for each commanded onset time. (C) The effect of commanded onset time on peak ML COM speed is shown for lateral and medial perturbations.