VP above ($\mathbf{VP_A}$) or below ($\mathbf{VP_B}$)?

A new perspective on the story of the virtual point.

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The spring inverted pendulum model with an extended trunk (TSLIP) is widely used to investigate the postural stability in bipedal locomotion [1, 2]. The challenge of the model is to define a hip torque that generates feasible gait patterns while stabilizing the floating trunk. The virtual point (VP) method is proposed as a simplified solution, where the hip torque is coupled to the passive compliant leg force via a virtual point. This geometric coupling is based on the assumption that the instantaneous ground reaction forces of the stance phase (GRF) intersect at a single virtual point.

The position of the VP modifies the hip torque profile, and therefore alters the gait characteristics. The existing literature considers the VP to be above ($\mathbf{VP_A}$) the center of mass (CoM), which is supported by the GRF measurements of human walking [1, 3] and running gait [1, 4]. In contrast, our work suggests that the VP has to be below the CoM to generate forward trunk motion observed in human running [5, 6]. Overall, our understanding of the VP method and its effect on the gait remains limited.

Our work highlights two major geometric regions, which classify the VP space and are divided primarily by the CoM-foot axis and by the hip-foot axis (see Fig. 1) [5, 6]. The position of the VP relative to the CoM-foot axis determines the direction of trunk rotation, whereas its position relative to the hip-foot axis determines the sign of the hip torque. We suggest that the choice of VP position shapes the energy distribution, and can be used to redistribute joint loads between the leg and hip. We show that $\mathbf{VP_A}$ reduces the kinetic energy fluctuations of the CoM, while a $\mathbf{VP_B}$ reduces the potential energy fluctuations. The $\mathbf{VP_B}$ leads to a synergistic work between the hip and leg, reducing the leg loading. However, it comes at the cost of increased peak hip torque. We show that these results are valid for both orthograde (upright) and pronograde (horizontal) trunk orientations (Fig. 1a vs. 1b), and are viable for running speeds between 4-10 $\mathrm{m\,s^{-1}}$.

The existence and feasibility of the VP remains controversial, and it is even less understood how effective the VP mechanism can be in accommodating disturbances in terrain. In our current work, we investigate the reaction of the VP mechanism to step-down disturbances, using a simplified simulation model of human running. We expect to obtain different balance responses for $\mathbf{VP_A}$ and $\mathbf{VP_B}$. Included is a snapshot from our preliminary results in Fig. 2 for $5\,\mathrm{m\,s^{-1}}$ forward speed.

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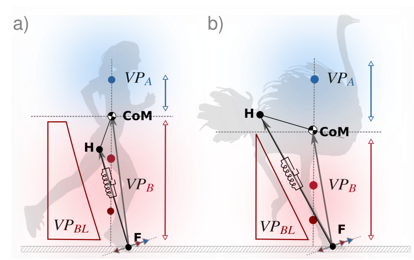

Fig. 1: The orthograde (a) and pronograde (b) TSLIP model and major regions for defining the VP position.

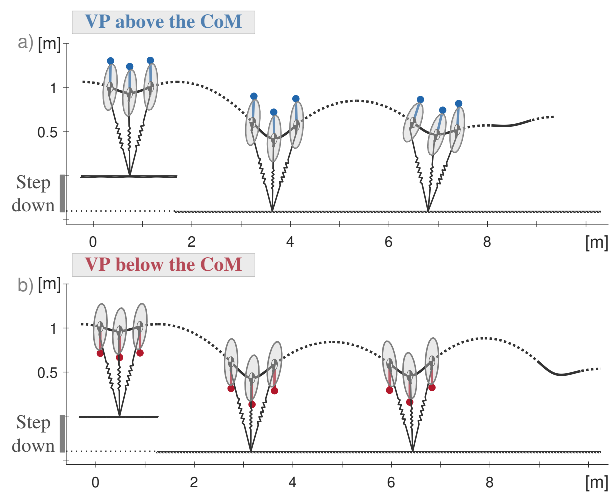

Fig. 2: The center of mass trajectories of the orthograde TSLIP model for $\mathbf{VP_A}$ (a) and $\mathbf{VP_B}$ (b) with a $30\,\mathrm{cm}$ radius. Plotted are the touch-down, mid-stance, and take-off states.

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