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Original article

Stability-maneuverability trade-offs during lateral steps

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ABSTRACT

Selecting a specific foot placement strategy to perform walking maneuvers requires the management of several competing factors, including: maintaining stability, positioning oneself to actively generate impulses, and minimizing mechanical energy requirements. These requirements are unlikely to be independent. Our purpose was to determine the impact of lateral foot placement on stability, maneuverability, and energetics during walking maneuvers. Ten able-bodied adults performed laterally-directed walking maneuvers. Mediolateral placement of the "Push-off" foot during the maneuvers was varied, ranging from a cross-over step to a side-step. We hypothesized that as mediolateral foot placement became wider, passive stability in the direction of the maneuver, the lateral impulse generated to create the maneuver, and mechanical energy cost would all increase. We also hypothesized that subjects would prefer an intermediate step width reflective of trade-offs between stability vs. both maneuverability and energy. In support of our first hypothesis, we found that as Push-off step width increased, lateral margin of stability, peak lateral impulse, and total joint work all increased. In support of our second hypothesis, we found that when subjects had no restrictions on their mediolateral foot placement, they chose a foot placement between the two extreme positions. We found a significant relationship ($p < 0.05$) between lateral margin of stability and peak lateral impulse ($r = 0.773$), indicating a trade-off between passive stability and the force input required to maneuver. These findings suggest that during anticipated maneuvers people select foot placement strategies that balance competing costs to maintain stability, actively generate impulses, and minimize mechanical energy costs.

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1. Introduction

Community ambulation involves frequent direction changes [1]. Even relatively straight walking tasks like navigating a city sidewalk require ongoing *lateral maneuvers* to avoid pedestrians and select desirable pathways. People use step width modulation to control mediolateral center of mass (COM) motion [2–5]. However, multiple mediolateral foot placement combinations can successfully maneuver the COM through turns [5,6], laterally-directed steps [7], and around obstacles [2]. Preferred foot placement strategy is influenced by age [5,7–10], neurologic injury [11], and task uncertainty [6,12]. During straight-line walking, there are interactions between mediolateral foot placement and both stability and mechanical energy cost [13]. These relationships remain unclear during maneuvers. We examined a biomechanical framework to assess the impact of mediolateral foot placement during maneuvers on passive stability and mechanical energy requirements.

Passive stability (the body's mechanical resistance to speed or direction changes) and maneuverability (speed or direction changes in response to a given control signal) are inversely related [14,15]. Adapting passively-stable walking mechanics negatively impacts maneuverability because self-initiated changes to gait will be indiscriminately resisted [14]: a greater impulse (control signal) must be generated to execute a given maneuver as passive stability increases. Thus, the ability to maneuver will be determined by both passive resistance to movement and the magnitude of the control signal that can be produced. In situations requiring locomotion

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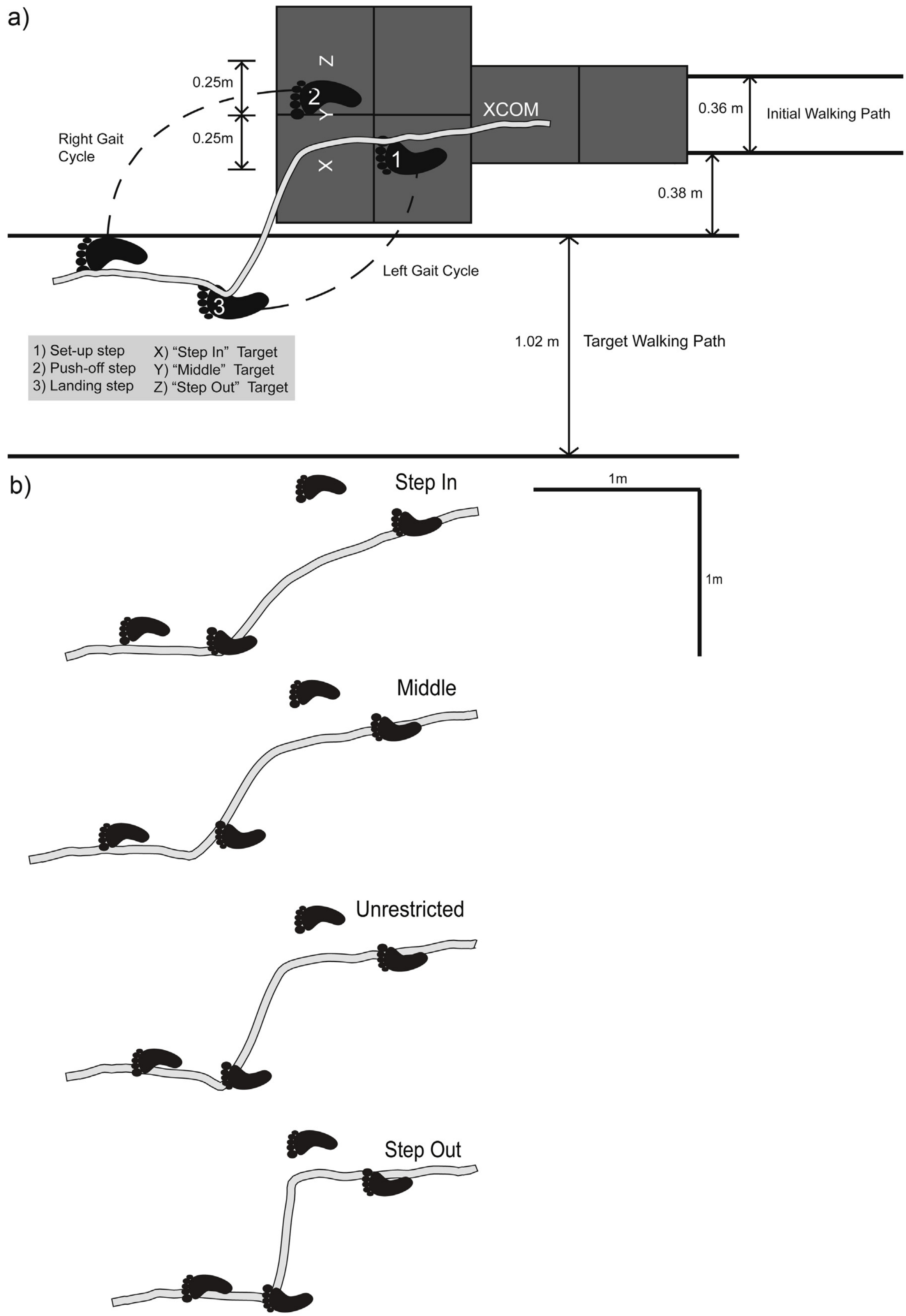

Fig. 1. (a) Subjects performed laterally-directed walking maneuvers. All maneuvers involved transitioning from an initial walking path to a target walking path located to the subject's left side. Mediolateral foot placement of the Push-off step was modified by instructing subjects to either step on specific targets; X) Step In, Y) Middle, and Z) Step Out, marked on the ground or to select their own preferred, unrestricted, foot placement. We analyzed lateral margin of stability of the left limb during the stance-phase of the Set-up step. We analyzed peak lateral impulse and joint work of the right limb during the Push-off step. A representative subject's extrapolated center of mass position and