Anterior-posterior margins of stability when stepping in/out of a moving walkway

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1. Introduction

The ability to adapt one's gait to a changing environment is a critical skill for a safe locomotion. Stepping in and out of a moving walkway is as a very simple experimental paradigm to assess this ability. It is also an ecological task that reproduces real-life situations, notably encountered in public transportations. However, if adaptations to other type of perturbations (stepping over obstacles, reaction to unexpected perturbations …) have already been studied, there is almost no literature about stepping in/out a moving walkway. Only Hsu et al. (2015) reported adaptations of the spatiotemporal parameters when stepping in the moving walkway (Hsu et al. 2015). No study present results about the margins of stability (MoS) although it is a well-known and consistent method to analyse such adaptations (Hof et al. 2005).

Therefore, the aim of this paper was to study the MoS during the transition step when the participant has one foot on the steady ground and the other on the moving walkway. Our hypothesis is that the anterior-posterior MoS will reveal adaptations to the change of speed.

2. Methods

Sixteen adults, 10 males and 6 females (27.9 ± 7.2 years old, 69.5 ± 11.9 kg, and 1.73 ± 0.08 m) with no self-declared gait impairment, gave their written consent to participate in the study. The experimental protocol was approved by the Gustave Eiffel University ethics committee.

A setup composed of an instrumented split-belt treadmill (Treadmetrix, Park City, USA) and two 2-m platforms positioned at each end of the treadmill was designed to replicate a moving walkway. The belt velocity was set at 0 m/s for a walking condition and at 0.5 m/s for the stepping in/out conditions. Participants were asked to walk across the walkway at their comfortable walking speed. Each condition was repeated at least seven times after a familiarisation period (the participants performed as many trials as necessary until they felt comfortable with the task).

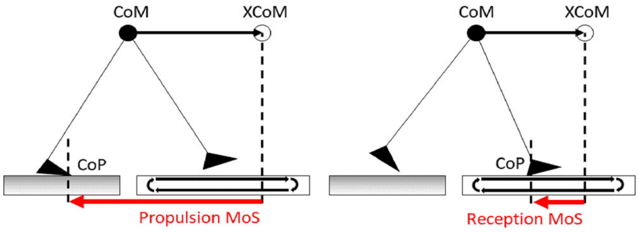


Figure 1. Definition of propulsion and reception MoS when stepping in the moving walkway.

The force data was captured from three force plates, two in the treadmill and one (Bertec, Columbus, USA) implemented in one of the platforms. The kinematics data was captured with 10 optoelectronic cameras (Qualisys, Göteborg, Sweden) using 13 markers for centre of mass (CoM) calculation (Tisserand et al. 2016).

The extrapolated centre of mass (XCoM) and its position with respect to the centre of pressure (CoP) (Hof et al. 2005) were used to compute the MoS vector (Equations 1 and 2):

$$\overrightarrow{\mathbf{MoS}} = \overrightarrow{\mathbf{CoP}} - \overrightarrow{\mathbf{XCoM}} \tag{1}$$

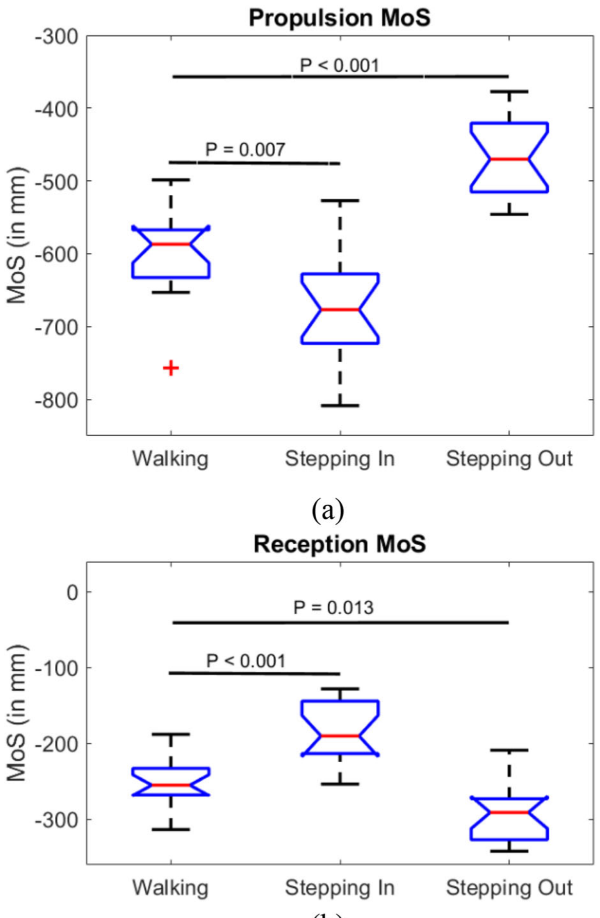
$$\overrightarrow{\mathbf{XCoM}} = \overrightarrow{\mathbf{CoM}} + \frac{\overrightarrow{\mathbf{v}_{/stance}}}{\sqrt{g/l}} \tag{2}$$

with l being the leg length, g the gravitational acceleration and $\overrightarrow{\boldsymbol{v}_{/stance}}$ the velocity of the CoM expressed in the stance foot frame (i.e. corrected by the belt velocity if the stance foot was on the moving walkway). The anterior-posterior component of the MoS vector (Equation 1) was computed at two instants of time (Figure 1): just before contralateral heel-strike for the trailing leg (named propulsion MoS) and just after contralateral toe-off for the leading leg (reception MoS). The propulsion and reception MoS captured the overall body dynamics just before (i.e. anticipation) and just after (i.e. adaption) the transition in/out the moving walkway. Note that the MoS must be negative to ensure a steady gait.

After checking for non-normal distributions of the averages across trials for each participant, Dunn–Sidak's tests were used to perform multiple comparisons between the propulsion/reception MoS in the walking condition and the stepping in/out conditions ($p < 0.05$).

3. Results and discussion

The self-selected walking speed of the participants, computed as the CoM velocity over three steps, was



(a)

(b)

Figure 2. Propulsion (a) and reception (b) MoS during the walking, stepping in, and stepping out conditions.

1.22 ± 0.05 m/s for the walking condition. In this condition, the median propulsion and reception MoS were −587 mm and −254 mm, respectively. As shown on Figure 1, it was expected to have a reception MoS of smaller amplitude.

Figure 2a shows that propulsion MoS for stepping in and out of the moving walkway were significantly different from the walking condition. The XCoM was placed, respectively, more anterior and less anterior from the CoP than during walking, resulting in an acceleration (stepping in) and deceleration (stepping out) of the CoM at the beginning of the transition step.

Figure 2b shows that reception MoS for stepping in and out of the moving walkway were significantly different from the walking condition. Conversely to the propulsion, the XCoM was placed, respectively, less anterior and more anterior from the CoP than during walking, resulting in a deceleration (stepping in) and an acceleration (stepping out) of the CoM at the end of the transition step.

The results demonstrate that the participants have anticipated the speed change, but that the adaptations needed further adjustments. Our hypothesis was therefore confirmed. Interestingly, for all participants, the adaptations tended to over-control the CoM velocity (i.e. more acceleration or deceleration than needed). The adjustments therefore corresponded to opposite variations of the CoM acceleration with respect to the walking condition. These adaptations and adjustments seem to correspond to mechanisms that can be captured with an inverse pendulum model (i.e. studying CoP, CoM, XCoM, and MoS) but other balance mechanisms such as angular momentum can be present in case of gait perturbations and these mechanisms were not studied here. The control of the swing foot while stepping in moving surface has been already studied in the literature (Hsu et al. 2015). The reported increased speed of the leading foot to match the belt velocity seems consistent with the increased propulsion MoS found in the stepping in condition of the current study.

Although the participants were young, healthy, and got familiarised with the task, stepping in and out of a moving walkway with a belt speed at 0.5 m/s remained a quite challenging task. This belt speed is a standard speed for moving walkway, i.e. about half the speed of a natural walking pace. Previous ergonomic studies of moving walkway operating in airports (Hawkins and Atha 1976) have reported potential balance problems (e.g. slight sway, convulsive jerks).

4. Conclusions

Adaptations of the anterior-posterior MoS were required to efficiently step in and out of a moving walkway. These adaptations tended to over-control the CoM velocity during the propulsion and needed further adjustments during the reception of the transition step. These results provide baseline data for future studies in the fields of transport (e.g. adequate belt speed for a moving walkway) or clinics (e.g. personalized training protocols for patients with stability/balance impairments).

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