Two different roles of the trunk segment during the anticipatory phase of gait initiation

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1. Introduction

Ensuring balance is vital for everyday movement. Gait initiation, the transition from quiet standing to a whole-body steady movement, is a common paradigm to investigate the quality of balance-movement coordination. During gait initiation, stereotyped anticipatory lower-limb muscle activations create a mechanical instability to generate a forward rotation of the whole-body before the first foot-off helping movement initiation (Crenna & Frigo, 1991).

However, this assumption was based only on the centre of pressure displacement and a linear inverted pendulum model of the whole-body, neglecting the rotational contribution of segments to the movement. When investigating the internal whole-body angular momentum (H_M) around the mediolateral axis during stepping, the body rotates backward before the first foot-off, mainly because of the large inertia of the trunk segment (Begue et al., 2021). However, differences might exist between stepping and gait initiation because stepping implies stopping the forward motion initiated at the first step.

During gait initiation, robust activations of trunk extensor muscles were recorded before the first foot-off (Ceccato, Sèze, Azevedo, & Cazalets, 2009). Yet it remains unclear whether these trunk muscle activations contribute to the whole-body forward acceleration, to the whole-body stabilisation (by limiting the forward H_M), or both. Adding mass to a segment can modify its inertia, enabling to explore its contribution.

Here, we have compared two different trunk mass conditions to highlight the contribution of the trunk segment to H_M (H_M^{Trunk}), and thus to the balance-movement coordination.

2. Methods

2.1. Participants and procedure

Nine healthy participants (5 males, 22 ± 2 years old) equipped with 60 markers placed on anatomical landmarks and standing with each foot on a force plate were instructed to initiate gait and to walk up to a mark placed five meters away. Initial feet location and location of the first stepping foot landing were marked on the ground, to ensure the repeatability of the starting position and of the whole-body centre of mass (CoM) velocity through conditions. Two conditions, presented in a randomised order, were tested: with and without masses (about 13% of their body weight total) added to the trunk segment. The additional masses consisted of rigid barbells placed at shoulder level, evenly distributed between the front and the back of the trunk. Additional markers were placed on the barbells to quantify their inertial parameters. Participants performed three trials in each condition and were familiarised with the task and the added masses before recording. Two force plates (Sensix) and 15 infrared cameras (Vicon) recorded ground reaction forces and marker 3D trajectories at 2000 and 200 Hz, respectively.

2.2. Data and Statistical Analyses

Marker trajectories were lowpass filtered at 10 Hz and used to create a 13 segments whole-body model (excluding hands). Segments CoM and inertia were computed according to anthropometric tables from (Dumas, Chèze, & Verriest, 2007). The whole-body CoM was computed as the weighted sum of all segment positions, and H_M as the sum of the segment angular momenta transferred to the whole-body CoM. The contribution of the barbells to H_M were added to H_M^{Trunk}. H_M and H_M^{Trunk} were normalised by the product of the height, the mass, and the square root of the gravity constant times the height of the participant (Begue et al., 2021). We analysed the anticipation phase of gait initiation, beginning when the forward whole-body CoM velocity exceeded the average +3 SD measured during quiet standing (0%), and ending at the first foot-off (100%, when the vertical ground reaction force under the swing foot was lower than 10 N). The influence of the additional masses on H_M and H_M^{Trunk} around the mediolateral axis was tested with a paired t-test using Statistical Parametric Mapping.

3. Results and discussion

There was no difference in the whole-body CoM velocity at toe-off (p=0.56). Both H_M and H_M^{Trunk} were

around zero from 0 to 30%, directed forward from 30 to 80%, and directed backward from 80% to 100% (Fig 1). These curves were similar for each participant, and not different between the two conditions (both p > 0.05).

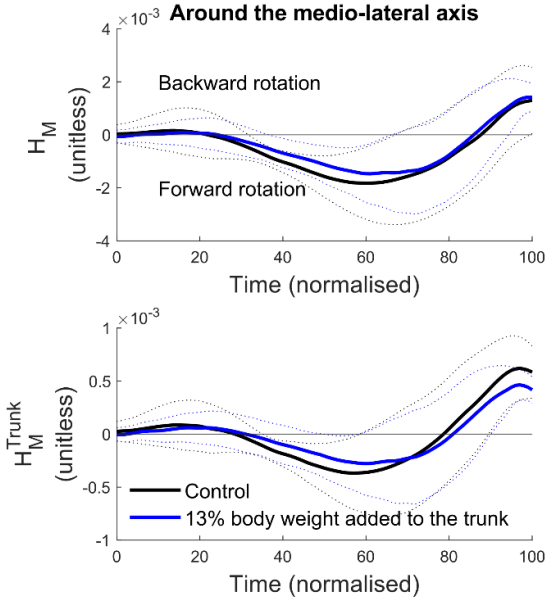

Figure 1. Average and standard deviations (solid and dashed lines) of H_M and H_M^{Trunk} during the two trunk segment mass conditions Credit: Romain Bechet

Despite different trunk segment masses, both H_M and H_M^{Trunk} remained similar between conditions during the anticipatory period of gait initiation. The absence of difference suggests that the magnitude of angular momentum is a variable controlled by the nervous system and confirms an important role of the trunk segment in balance-movement coordination. Yet, this remains to be confirmed and future studies should characterise the kinematic adjustments required to achieve the same dynamics.

Our results also suggest two successive roles for the trunk segment during gait initiation. During the first part of the transition, the trunk segment largely contributes to the forward whole-body rotation initiation. Then, once motion is initiated, the trunk segment seems to act as a stabiliser, reducing and reversing the forward rotation of the whole-body. This could help stabilising the head during the movement (Pozzo, Berthoz, & Lefort, 1990), and help limit the forward angular momentum magnitude to avoid an excessive mechanical instability. Better characterising muscle activations contributing to this counter-rotation would clarify the role of trunk muscles during transitions and may help characterise the difference in population at risk of falling.

4. Conclusions

In summary, we found no difference in H_M when adding mass to the trunk, suggesting the trunk dynamic is a controlled variable of the balance-movement coordination during the transition. During the first phase of the anticipatory period, the trunk segment seems to contribute to the forward whole-body H_M initiation, but then seems to act as a stabiliser to limit the forward whole-body H_M.

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Conflict of Interest Statement

None of the authors have competing interests.

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