BALANCE RECOVERY IN THE DOUBLE SUPPORT PHASE DURING PERTURBED WALKING

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I. INTRODUCTION

Exoskeleton walking increases the relative time spent in the double support phase (DSP). It is therefore crucial to control balance when both feet are on the ground. Healthy humans have excellent balance capabilities to avoid falling. The centre of pressure (CoP) describes the control of the centre of mass (CoM) movement [1]. The range of possible CoP locations in the DSP is determined by the foot placement at the end of the preceding single support phase. This study focuses on the CoP modulation during the DSP in the control of the CoM state.

II. METHODS

CoP trajectories in response to pelvis perturbations were extracted from an existing data set by Vlutters et al [2]. Anteroposterior and mediolateral perturbations with magnitudes up to 16% of the body weight were given at the moment of toe off. Parameterized CoP trajectories were generated with a spline function based on the experimental CoP trajectories, examples are shown in figure 1. Parameterization was done as a function of 1) the duration of the DSP, 2) the amplitude of the CoP, and 3) percentage of the amplitude reached halfway the DSP (= midpoint). The parameters were varied within a range equal to the standard deviation around the mean value obtained from the experimental data. The generated trajectories were used in model simulations of the CoM during the first DSP following the perturbation. A simple inverted pendulum model, relating the horizontal distance between the CoP and CoM to CoM acceleration, was used to assess the effectiveness of the CoP modulation in counteracting perturbation induced CoM velocity changes [3].

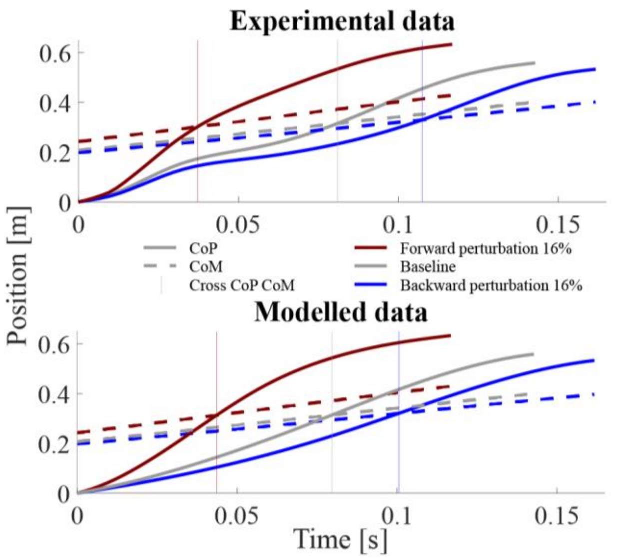

Fig. 1. ToP) The CoP and CoM position of the experimental data; Bottom) The generated CoP input and CoM output of the model.

III. RESULTS

The model outcome corresponds with the experimental data, figure 1. All the three CoP parameters are linearly related to the change in CoM velocity over the DSP, in both the experimental and modelled data. Changes of the midpoint resulted in larger variations in the modelled Δ CoM velocity, compared to those resulting from changes in the duration or amplitude, see figure 2.

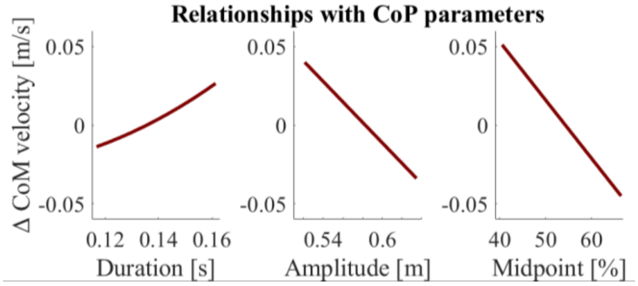

Fig. 2. Relationships between the CoP parameters and the Δ CoM velocity.

IV. DISCUSSION

A simple inverted pendulum model was able to model representative CoM trajectories from the generated CoP trajectories as input. To control the CoM velocity after a perturbation, subjects used all CoP parameters. However, in the experimental data these parameters were also related with each other. When uncoupling the effect of these parameters in the model, the shape of the CoP trajectory, represented by the CoP shift that is reached halfway the DSP, had the largest influence on the changes of the CoM velocity during the DSP. Shifting the load earlier or later to the leading leg helps in increasing or decreasing the CoM velocity. This will help in counteracting the effect of the perturbation and returning to the baseline CoM velocity.

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