A biomechanical quantification of an effective balance recovery strategy in free-standing females and males using OpenSim

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I. INTRODUCTION

Free-standing occupants on public transport vehicles are subjected to driving manoeuvres that can cause postural instabilities, in turn increasing the risk of falling and subsequent injuries [1]. In a series of volunteer tests, 24 volunteers (11 females, 13 males) were subjected to different magnitudes of acceleration and braking perturbations on a linearly moving sled, similar to those on public transport. From these tests, different balance strategies were identified, characterized and evaluated qualitatively through video analyses. One strategy, labeled as the *fighting stance* (Fig. 1), was characterized by a lower body positioning utilizing a weight-bearing leg (front leg) and a supporting leg (rear leg). The *fighting stance* had a predominant effectiveness over the other identified strategies to counteract the perturbations, evidenced by the users having the highest success rate. The *fighting stance* facilitates balance recovery by incorporating a stance to counteract stepping during a perturbation. As the *fighting stance* shows great potential in increasing the ability of public transport passengers to recover balance, further investigation of this strategy was needed to understand the effectiveness and how it can be implemented in practice to increase perturbation tolerances. In the current study, the *fighting stance* was assessed using OpenSim, an open-source platform commonly used for musculoskeletal modelling and simulation of movements [2], to obtain individual-specific anthropometries and inverse kinematics (IK) based on motion capture data (Oqus 3+, Qualisys, Gothenburg, Sweden). The aim of this study was to provide baseline biomechanical knowledge to understand the effect of different perturbation pulse severities on the execution and the resulting balancing outcome of the *fighting stance*.

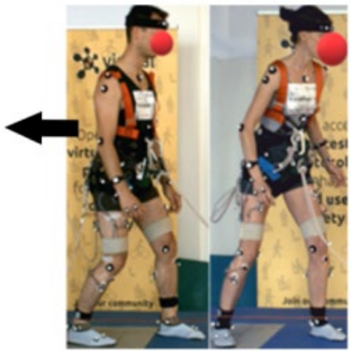

Fig. 1. *Fighting stance* in rearward direction. Arrow indicates sled motion.

II. METHODS

A full-body musculoskeletal model of an average male known as the Rajagopal model [3] was used to perform scaling and IK on one female and one male volunteer executing the *fighting stance* as their primary recovery strategy. The marker coordinate data used were captured from the volunteer tests during two different acceleration pulses, the *baseline* and the *higher jerk* are described in Table I.

TABLE I
PERTURBATION PROFILES IN THE VOLUNTEER TESTS

Profile name	Magnitude [m/s^2]	Jerk [m/s^3]	Rise time [s]	Duration [s]
Baseline	1.5	5.6	0.4	2.25
Higher jerk	1.5	11.3	0.2	2.15

The final anthropometry and marker placements in OpenSim were compared to the documentation from the experiments. Scaling was iterated until root-mean square (rms) and maximum marker errors according to the guidelines in the OpenSim documentation (scaling: rms < 1 mm, max < 2 mm; IK: rms < 2 mm, max 2–4 mm) were achieved. The ankle, knee and hip angles were used to characterize the *fighting stance* execution.

III. INITIAL FINDINGS

Joint angle responses for the ankle, knee and hip for the female and the male volunteer were obtained from the OpenSim simulations. Figure 2 displays the balancing reaction where the *fighting stance* was executed.

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Positive slope of the curve indicates joint flexion and negative slope indicates joint extension. The main finding was the difference in joint angle response to the acceleration pulses, where *higher jerk* induced a faster joint angle response in the left leg for both volunteers (at 0.4—0.7 s for all left joints). Compared to the *baseline* pulse, the joint angular response in *higher jerk* perturbations tended to a more constant value at the end of the pulse.

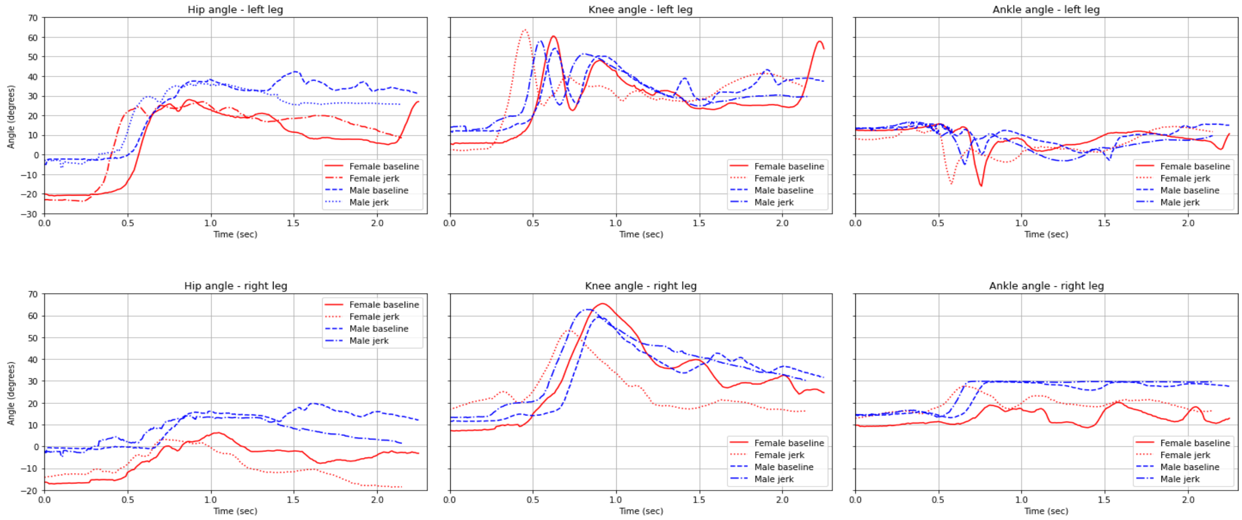

Fig. 2. Joint angle responses for the ankle, knee and hip for the female and the male volunteer.

IV. DISCUSSION

The initial findings of this study were presented as the time history of the lower-body joint angles relevant for characterizing the *fighting stance*, with focus on the rearward-facing direction for the two pulse severities. Figure 2 displays the left hip and knee flexion of the front leg, before a longer duration of knee flexion of the rear (right) leg (after ~0.7 s for *baseline*, and ~0.5 s for *highest jerk*). This positions the left leg (illustrated in Fig. 1) in front of the body to initiate the *fighting stance*, increasing the base of support and dynamic stability [4-7]. The ankle acts to stabilize the foot to the ground, with the rear leg having a flexed knee and dorsi-flexed ankle (positive ankle angle), finalizing the *fighting stance* execution. The *fighting stance* was executed more effectively in the *higher jerk* than *baseline* as displayed by the more stable motion patterns towards the end of the perturbation, which indicates increased postural stability and balance recovery.

It is therefore hypothesized that the *higher jerk* might indicate a perturbation that is sufficient to induce a strong initial reaction, provoking an effective biomechanical response to counteract the perturbation when using the *fighting stance*, without exceeding the jerk tolerance. The synergies among the lower-body joints, as well as further perturbation profile parameters, should be studied in more detail for the *fighting stance*. This might provide knowledge to assess optimal driver manoeuvres and prescribed manoeuvres of autonomous vehicles for passenger safety on public transport. The response of the volunteers applying the *fighting stanc*e should be compared to other balance strategies to assess the various strategies' effectiveness in terms of injury risk due to loss of balance. Derived biomechanical data from musculoskeletal modelling software tools can benefit the development of active human body models (A-HBMs) to simulate free-standing passengers subjected to various perturbations on public transport. The scaled model and IK data from this study provide the necessary material to simulate inverse dynamics and muscle activation in OpenSim. Conclusively, the joint angles presented here can be used to position a HBM into a representative initial posture for impact simulations to assess injury risks during free-standing scenarios on public transport.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

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