Volunteer Fall Experiments in Principal Fall Directions During Bus Braking Manoeuvres

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I. INTRODUCTION

Non-collision bus incidents are often caused by sudden braking and accounts for 50–70% all bus-related injuries [1–3]. Head and extremity have consistently been shown to be the most frequently injured regions [1–4]. Recently, we identified that the most common bus-related injuries were, for example, concussion and traumatic haemorrhages (head), distal radius fractures (wrist), and both proximal femur and intertrochanteric fractures (hip) [4]. However, no previous studies have characterised the fall and impact configurations in which such injuries arise. While falls from standing height have been extensively studied through volunteer experiments [5, 6], the perturbation pulses to induce falls are limited in laboratory settings in terms of shape and duration compared to bus driver manoeuvres [7]. Furthermore, for public transport purposes, only balance recovery experiments have been studied [8]. However, these previous experiments lack biomechanical characterisations related to fall direction, as well as specific impact locations that leads to potential hip fracture risks [6, 9].

The development of London's Bus Safety Standard has led to increased use of CCTV analyses to investigate bus passenger injuries [10]. However, these studies have not presented injury mechanisms in relation to fall direction, nor impacted body regions that resulted in specific injuries. To understand fall injury mechanisms related to bus manoeuvres, a series of field fall experiments in three principal directions – forward, sideways, and backwards, was conducted with volunteers using non-emergency braking manoeuvres. The aim of this study was to investigate head, hip, and wrist fall impact biomechanics.

II. METHODS

Young adults were recruited to reduce the risk of triggering fear of falling (more common among older adults). A total of 19 healthy young adults (20–43 years old) were recruited; 7 women (mean height = 168.4 cm (SD = 4.1)) and mean weight = 67.4 kg (SD = 9.6)) and 12 men (mean height = 182.0 cm (sample SD = 4.4, due to missing data for one volunteer) and mean weight = 74.1 kg (sample SD = 9.2)). The following exclusion criteria were used: current injury or neurological disorder, re-injury risks, fear of fall, motion sickness, discomfort with falling. A truck with internal cargo dimensions of 2.5 × 7.3 m (width × length) was used instead of a bus to avoid contact with interior structures such as seats or handrails. The volunteers fell onto 30 cm thick gymnastic mattresses, wearing helmets and wrist guards for increased perceived safety. The study was approved by the Swedish Ethical Review Authority (Dnr 2024-08679-01). All participants signed an informed consent form.

To trigger passive falls, two braking severities were constructed. The truck accelerated to a constant velocity of 20 and 25 km/h, respectively, and then decelerated to targeted average braking magnitudes of 2.5 m/s^2 and 3.5 m/s^2, respectively. Each volunteer was subjected to three fall directions relative to the direction of travel (parentheses denote the short names of the pulses): forward (fw1 and fw2), sideways (landing on the left hip, sw1 and sw2), and backward (bw1 and bw2). The volunteer was instructed to place their feet shoulder-width apart, hold onto a handrail and – as the instructor asked the volunteer to let go (at constant truck velocity) – try to maintain the original stance without stepping to induce a purely passive fall. In rare cases, trials had to be re-done, for example, if a trial did not result in a passive fall due to compensatory stepping, if deliberately performing a practiced fall technique, or if the pulse magnitude deviated from the targeted average.

Two GoPro Hero 10 cameras captured 1) a front angled view and 2) a side view camera angle, in 120 frames per second. Wearable inertial measurement units (IMUs) (Movesense Flash, 104 fps) were attached to the forehead, hip (close to the Anterior Superior Iliac Spine, ASIS), wrists, elbows, torso (between clavicles), and behind the knees to measure the fall kinematics. This short communication presents a qualitative assessment of the head, hip, and wrist impacts from the recorded videos to provide the characterisation of impacts depending on the fall direction. Two categories were used to characterise the head impacts; soft and direct head impact (the former indicated contact and the latter a clear rebound motion). Specific hip impacts were characterised similar to [9]: lateral, posterolateral, and lateroposterior (sideways impacts), lateroanterior and anterolateral (forward impacts), and posterior impacts (backward falls).

III. INITIAL FINDINGS

The volunteers completed all fall trials. Nine of 19 volunteers had to re-do at least one trial. Only one had to re-do two different trials, due to compensatory stepping and intentional rotational technique to break the fall. In

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general, the volunteers felt that both braking severities were hard to withstand without compensatory stepping. Eighteen of the 19 volunteers reported that they would likely be unable to regain balance during the higher-severity braking. Figure 1 shows the impact rates among the volunteers for each fall trial. Head impacts were most common in sideways falls (37% in sw1 vs. 53% in sw2) and backward falls (37% in bw1 vs. 63% in bw2). However, direct head impacts were more evident for bw2 (50%) than sw2 (20%). Wrist impacts with outstretched hands increased with braking severity and were most common in forward falls, clearly catching the falls to avoid head impact. Hip impacts were less common in forward falls due to the wrists braking the fall. Seated impacts only occurred in backward falls. Sideways falls showed a variety of hip impacts (Fig. 1 and 2). Varying proportions of specific hip impacts were observed: posterolateral impact (31% in sw1 and 44% in sw2), lateral impact (19% in sw1 and 33% in sw2) and lateroposterior impacts (44% in sw1 and 22% in sw2), and only one anterolateral case.

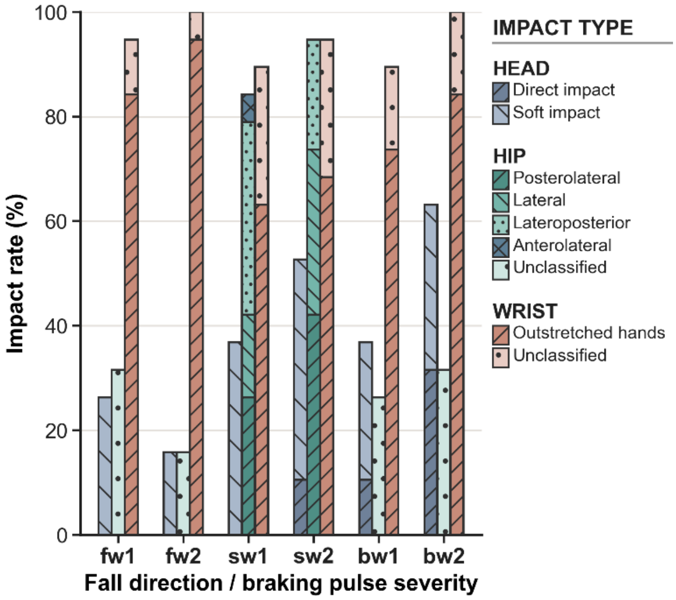

Fig. 1. Impact rate during different fall trials.

Fig. 2. Fall configurations for specific hip impacts.

I. DISCUSSION

A first series of field fall experiments was performed using realistic braking manoeuvres to induce passive falls in three principal fall directions – forward, sideways, and backwards. For the trials that had to be re-done, additional or clearer instructions to the volunteers to stand firm on the platform without taking a step, resulted in passive falls without fail. Our qualitative analysis displays the impact rate of three body regions during six fall trials. The analysis demonstrates the clear variety in hip impact configurations, which should be considered to improve the precision of specific injury risks, e.g., femoral neck vs. intertrochanteric fractures. However, to understand the fall impact severity in relation to the tested braking pulses, quantitative analysis using IMU data is needed which could then be compared to regular falls from standing height. Upcoming analyses using IMU data will provide initial fall kinematics, which together with the impact configurations are needed to accurately simulate realistic falls using finite element human body models. Future experiments should explore higher severities, and potentially also evasive manoeuvres to include the rotational vehicle dynamic components.

II. ACKNOWLEDGEMENTS

This project is funded by the Swedish Foundation for Strategic Research (SSF), no. FID22-0023, and Skyltfonden, the Swedish National Road Administration, no. 2024/24429. The authors are grateful for the volunteers' participation. Special thanks to VTI colleagues: Stina Larsson and Ary P. Silvano for their support with the volunteer test trials, and to Mikael Bladlund for the consistency in executing the braking manoeuvres.

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