



Non-collision incidents on buses due to acceleration and braking manoeuvres leading to falling events among standing passengers

Ary P. Silvano^{a,*}, Maria Ohlin^{a,b}

^a Swedish Road Transport Research Institute, VTI, Olaus Magnus väg 35, 581 95, Linköping, Sweden

^b Department of Food and Nutrition and Sport Science, University of Gothenburg, Gothenburg, Sweden



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ABSTRACT

Background: On public transport buses, standing passengers are subject to acceleration and braking driver manoeuvres which may lead to a falling event.

Purpose and procedures: This study investigates the characteristics of such events connected to driver manoeuvres (i.e., acceleration or braking), passenger conditions (i.e., boarding, travelling, alighting), and injury severity. The data for analyses comprise three and a half years (2015–2018). All passengers were standing at the time of the fall event and were treated at hospital emergency departments (ED) after the falling event.

Findings: The results highlight aspects which may need further attention. For example, the involvement of females is not only high for the 65 + age group, this is also the case for younger age groups which indicates that acceleration/deceleration threshold values for sustaining balance may differ by gender. Furthermore, driver manoeuvres and passenger conditions are important characteristics impacting the mechanisms of falling differently. In acceleration manoeuvres, older passengers (aged 65+) are most often involved in a fall immediately after boarding, whereas falls during braking manoeuvres are most common while travelling, and mostly involving the 25–64 years-old age group.

Conclusions: These findings may indicate that acceleration and braking manoeuvres should be studied separately. It is worth noting that driving style might influence the risk of losing balance for standing passengers, and shortening the time to get seated can be beneficial for reducing the risk of falling, especially for the elderly users after boarding the bus.

1. Background

The study is part of the project VIRTUAL (<https://projectvirtual.eu/>) which has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768,960. The overall objective of VIRTUAL is to improve the safety of urban road users by providing procedures and open access tools to assess the benefit of novel safety systems. The goal is to establish a European based global hub for Open Source Virtual Testing freely accessible on the internet. Open Source Human Body Models of both female and male users will be developed in a format that is scalable to represent all different ages and sizes for car occupants, vulnerable road users, and users of public transport (PT) systems (e.g., train, subway, tram, buses).

In Work Package 5, Virtual strives to improve the traffic safety of standing passengers in public transport vehicles by developing virtual testing models. The new developed standing Human Body Models will be used to model falls in public transport vehicles due

* Corresponding author.

E-mail address: ary.silvano@vti.se (A.P. Silvano).

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to non-collision events. Specifically, the objective is three-fold (i) identify the characteristics of passengers involved most frequently in non-collision injuries, (ii) identify factors where acceleration and braking manoeuvres led to falls resulting in injuries of the standing passenger, and (iii) characterise acceleration and deceleration properties of PT systems (e.g., magnitude, duration). These results will be used as input for developing the scenarios of the volunteer tests (e.g., gender, age, standing positions, acceleration/deceleration properties) to gather information about body kinematics relating to acceleration and braking manoeuvres to develop the standing Human Body Models. This paper includes the results of the data analysis of standing passenger falling events on buses connected to driver manoeuvres in non-collision incidents (i.e., acceleration or braking).

2. Introduction

Statistics show that injuries sustained on buses and coaches represent a public health problem which ought to be addressed (i.e., buses serving urban traffic and coaches dedicated for long distance traffic). For example, in a revision of all traffic fatalities for eight EU countries, PT casualties accounted for between 0.1% and 1.0% of the fatalities (Albertsson and Falkmer, 2005). In a Swedish study, Björnstig et al. (2005) found an incidence of two injured passengers per 10,000 inhabitants, with an average of 28 injured passengers annually after analysing emergency department data for a period of ten years (1994–2003). Generally, accidents involving buses and coaches are classified into collision and non-collision incidents (Björnstig et al., 2005). Collision incidents have been categorised into collision with another vehicle or a single-vehicle collision, (i.e., driving off the road). Non-collision incidents have been classified based on whether the vehicle was stationary, (i.e., a passenger falling while boarding/alighting) or the vehicle was moving, (i.e., a standing passenger falling due to a hard acceleration or an emergency braking) (Albertsson and Falkmer, 2005; Björnstig et al., 2005). It is also reported in the literature that buses have the highest longitudinal acceleration (2.5 m/s^2) as well as the highest lateral acceleration in curves and while swerving from bus stops (4 m/s^2) (Graaf and van Weperen, 1997). In a recent study, the characteristics (e.g., maximum, duration) of bus acceleration and deceleration signals were identified. Kirchner, Schubert, and Haas (2014) found in real-world buses that acceleration situations are longer and have smaller maximum compared to deceleration situations (acceleration: max = 1.4 m/s^2 , duration = 13.6 s; deceleration: max = 1.8 m/s^2 , duration = 9.8 s). These results are much higher in comparison to the thresholds found for maintaining balance while facing forward or backward to the travel direction. Graaf and van Weperen (1997) found that these thresholds during acceleration perturbances were 0.54 m/s^2 and 0.61 m/s^2 , for forward and backward facing respectively. They also found that jerking (i.e., change in acceleration per unit of time, m/s^3) is of great concern as a source of destabilisation and Kottenhoff and Sundström (2011) found that jerk impacts the ride comfort of bus users negatively. This indicates that on bus trips passengers are exposed to acceleration levels which generally surpasses the thresholds to maintain balance.

Barnes et al. (2016) studied injuries to older bus users in the UK for all type of accidents (e.g., collision with other vehicles, single collision). The authors found that users aged 60 + accounted for 8.4% of all 60 + injured passengers. They also found that the proportion of serious injuries was higher for 60 + users of 9.6% compared to the average of 5.9% for all ages. According to Björnstig et al. (2005), the group most often subject to falls on buses and coaches is characterised by their advanced age and by female users representing the largest group. The authors explain this pattern as the result of older female users travelling more frequently on PT and generally having a longer life span compared with male users. A British study by Kirk et al. (2003) found a similar pattern involving fatally and seriously injured passengers, where female passengers represented 74% of non-collision injuries, of whom 58% were above the age of 60. In Israel, Halpern et al. (2005) found a similar trend in non-collision injuries of a high percentage of incidents involving females (72%) and females aged above 55 (56%). In another British study, Kendrick et al. (2015) reviewed the literature and also found that older people and female users were overrepresented in injuries occurring while standing, moving, and waiting to alight buses. Emergency braking has been identified as one of the main factors in fatal non-collision accidents, causing approximately one third of all fatal injuries (Albertsson and Falkmer, 2005; Kendrick et al., 2015; and Halpern et al., 2005). With regard to injured body regions, Kendrick et al. (2015) found that the most commonly affected body regions involved the upper/lower limbs. Similarly, in the Swedish study by Björnstig et al. (2005), the upper limbs represented the most affected body region (27%), followed by the head (23%) and lower limbs (21%).

Studies in laboratory environments on avoidance and recovery tasks (e.g., stepping, step over, turn, stop) show that there are age and gender differences when attempting to maintain and recover balance (Schultz et al., 1997; Thelen et al., 1997). Schubert et al. (2017) studied the biomechanical demands of older passengers on buses in controlled conditions. Elderly people show lower threshold values for maintaining balance compared to young people. These threshold limits change as age increases due to the deterioration of sensory functions (Horak, 2006). Karekla and Tyler (2018) conducted gait analysis to study age and gender differences on bus passenger while 'walking' on a moving bus. They found that elderly female users needed more time with their feet on the ground to compensate their balance during acceleration perturbations. Moreover, bus acceleration perturbations cannot be anticipated easily by bus passengers and may result in a fall or near-incident (Schubert et al., 2017). Consequently, this may have negative effects on the overall travel experience, especially for elderly people, who may change their attitude toward public transport, i.e., stop using public transport (Schubert et al., 2017). According to the literature, the best strategy to adopt as the vehicle starts moving is to stand sideways in relation to the travel direction (Sarraf et al., 2014), and to place the handrail as high as possible, which would provide better control over the destabilisation sources (Komisar et al., 2018).

Whether female users travel more or longer than their male counterparts is important to establish to estimate injury risks (i.e., higher exposure). According to the Swedish national travel survey (RVU, 2015–2016), the total distance travelled on average by public transport (e.g., train, subway, tram, bus) per day by female and male users for all age groups is 6 km, (i.e., the average by gender for all age groups together does not differ). Age groups span from 6 to 84 years-old in steps of 10 years for each group.

However, there are differences between female and male users. For instance, in the working age group of 25–64 years-old, female users travel on average a total distance of 7 km per day on public transport, while the corresponding distance for male users is 5 km. Surpassing the working age ($> = 65$), the total distance travelled by public transport reduces significantly for both female and male users which averagely equals 2 km. In retirement, female users still travel on average 2 km further by public transport compared to male users up to 74 years-old. For the 75-84 years-old age group the male users travel longer by 1 km.

The aim of the present study was to identify factors and describe events where acceleration and braking manoeuvres led to falls, resulting in injuries on buses in Sweden, particularly focussing on falls of standing passengers in non-collision incidents while on a moving bus. This paper is organised as follows: Section 2 describes the data and methods used, Section 3 presents the results of the study, Section 4 discusses the results and Section 5 concludes the study.

3. Material and methods

Hospital reported data from the Swedish Traffic Accident Data Acquisition (STRADA) for the period January 2015 until August 2018 were used to identify events where individuals had sustained injuries as bus passengers (all type of crashes, $n = 1172$).

STRADA is a database with national coverage that contains information related to road traffic accidents collected from hospital emergency departments (ED) and police reports. As the information on sustained injuries is only reported by hospital EDs, not by the police, only data from hospital EDs were used in the present study. Hospital data collection for STRADA was initiated in 2003 and national coverage has gradually increased. In 2013, all but two hospital EDs reported to STRADA and since 2016 all ED hospitals are included. Hospital reports normally include a number of parameters describing the crash/incident (brief description of the accident/incident, crash type, location including coordinates, etc.), personal information about the patient (age, gender, use of protective equipment, etc.) and full diagnosis classified according to the AIS 2005 and MAIS scale (AAAM, 2005) and the International Classification of Disease (ICD-10-SE) (National Board of Health and Welfare, 2011). The AIS scale classifies each specific injury a passenger has sustained (i.e., an injured passenger may have multiple injuries) from 1 to 6 (minor injury to maximum injury). The highest AIS score for a person with multiple injuries is called the Maximum AIS (MAIS), (Tranportstyrelsen, 2018).

Each hospital report contains a written free-text description of the crash/incident which is gathered by trained personnel. These descriptions were analysed to identify events of standing passengers having experienced a fall due to the bus accelerating or braking ($n = 316$). This means that other falling events, such as falling while boarding or alighting a stationary bus, were not included in the analysis. Classifications were made both related to driver behaviour (i.e., hard acceleration or braking) as well as actions of injured passengers (i.e., standing while travelling, standing after boarding, or standing before alighting). Boarding in this case means that the passenger has boarded the bus but has not yet sat down. Alighting means that the passenger has moved from the seat and is standing while waiting for the bus to arrive at the bus stop. There is also information on STRADA to cross reference whether the injured passenger was standing.

The data were analysed using descriptive statistics. An explorative analysis was first conducted on the dataset by gender, age group ($< = 15$, 16–24, 25–64, 65+). Injury distributions were computed, and injury severity in terms of MAIS, was further investigated in relation to age, gender, as well as driver and passenger behaviour and number of care days in hospital. When appropriate a contingency table analysis was conducted carrying out a χ^2 test with alpha level 5%. Additionally, we investigated whether certain user groups might be more vulnerable to falling events, for example, passengers with walking frames. Injury severity was classified into two groups as follows, MAIS 1 (minor injury) and MAIS 2+ (from moderate to severe injury). The MAIS 0 classification in the dataset corresponds to uninjured or uncertain injury. These cases were not included in the analyses ($n = 29$). Lastly, some examples of common situations, described by passengers, which led to falling events, are given.

4. Results

4.1. All injuries, age and gender

In the studied period, there was a total of 1172 injured bus passengers in all crash types (e.g., vehicle-vehicle crashes, single-vehicle crashes, non-collision incidents). Table 1 shows the results classified by gender. Non-collision falling events due to hard acceleration or braking manoeuvres, classified as MAIS 1 or higher, account for 316 cases. This represents 27% of all crash types for injured bus passengers.

In Table 2, the results were further classified by age groups. For all crash types, the highest number of female users involvement was found in the 65 + age group ($n = 369$) representing 80% of the age group, compared to their male counterparts ($n = 95$). Likewise, the results due to non-collision events show as well a high involvement of female users compared to male users for all age

Table 1
All crashes vs. non-collision falling events.

Injured by gender and collision type	All crash types injuries	Non-collision injuries
Female users	879	255
Male users	293	61
Total	1172	316 (27%)

Table 2

All crashes vs. non-collision falling events by gender and age.

Injured as passenger on bus, all crash types	Female users	Male users	Percent female per age group
	n	n	%
< = 15	57	40	59%
16–24	105	34	76%
25–64	348	124	74%
65+	369	95	80%
Total	879	293	1172
Injured on bus by fall due to braking/acceleration, non-collision injured	n	n	%
< = 15	6	4	57%
16–24	22	2	87%
25–64	99	20	86%
65+	128	35	79%
Total	255	61	316

groups. The highest number of falling events is for the female group aged 65+ (n = 128), representing 79% of the age group. This age group shows the highest male involvement as well (n = 35). The number of fallings due to non-collision events reduces for the other younger age groups, however, the proportion of female involvement remains high, 87% and 86% for the brackets 16-24 years-old and 25-64 years-old groups, respectively. For those aged 15 or younger, the results show higher female involvement as well compared to males, though the percentage is much lower (57%).

4.2. Driver manoeuvre and passenger condition

Driver manoeuvres have been categorised into two conditions, (i.e., hard acceleration and hard braking manoeuvre). Passenger condition has been categorised into three conditions as follows: (i) standing after boarding looking for a seat 'boarding', (ii) standing waiting to alight 'alighting', and (iii) standing while the bus is moving 'travelling'. Thus, the dataset was classified into driver manoeuvre and passenger condition. Table 3 shows the results. The most common driver manoeuvre in fall events is a hard braking manoeuvre (62%), whereas hard acceleration accounts for 38% of the falling events. For passenger condition in braking manoeuvres the most common fall situations were in the travelling passenger condition and those in the process of alighting. Whereas boarding passengers were mostly affected by harsh acceleration manoeuvres whilst attempting to get seated.

The results further classified by age groups are exhibit in Table 4. The results show that more than 50% of falling events belong to the 65+ age group. For this age group, the falling events occurred most frequently after boarding (n = 78). The second age group involved is the 25-64 years-old age group that accounts for 38% of the falling events, though the most common falling event occurred while travelling (n = 44), followed closely by boarding (n = 38). These two age groups account for 89% of the falling events. The results also show that boarding shows the highest number of falling events, followed by travelling. Lastly, the number of falling events in the alighting passenger condition shows fewer events. Though the percent involvement is of concern (20%).

4.3. Distribution of injured body regions and injury severity

Fig. 1 shows the distribution of injured body regions for all injuries regardless of severity (n = 456) among female and male passengers who fell due to a hard acceleration or braking manoeuvre. The most common injury for both female and male passengers are external injuries (i.e., superficial injuries such as wounds and bruises, regardless of injury location), followed by injuries to the upper/lower extremities and head injuries. Male users showed a slightly higher proportion of lumbar spine injuries.

The Maximum AIS scale was used to describe the overall injury severity (MAIS 1 = minor; MAIS 2 = moderate; MAIS3+ = severe). Table 5 shows the results classified by injury severity. Most falling events were of low injury severity, where the majority (68%) was a MAIS 1 injury. Moderate injury severity accounted for 29% (MAIS 2). No significant difference was found comparing the proportion of MAIS 2+ injured among males (41%) and females (30%). (p = 0.09). A Contingency table was carried out with a χ^2 test at alpha level 5%. Moderately injured (MAIS 2+) were more often people above 65 years of age (Table 5).

Table 5 shows further that there were in total ten injured passengers who sustained at least one injury of MAIS 3. Six of them were

Table 3

Driver manoeuvre and passenger condition.

Driver manoeuvre	Passenger condition				Total
	Alighting	Boarding	Travelling	Unknown	
Acceleration	9	99	6	6	120 (38%)
Braking	56	24	96	20	196 (62%)
Total	65	123	102	26	316

Table 4
Falling events, passenger condition, and age groups.

Passenger condition	< = 15	16–24	25–64	65+	Total
Alighting	2	4	23	36	65 (20%)
Boarding	3	4	38	78	123 (39%)
Travelling	4	14	44	40	102 (32%)
Unknown	1	2	14	9	26 (9%)
Total	10 (3%)	24 (8%)	119 (38%)	163 (51%)	316

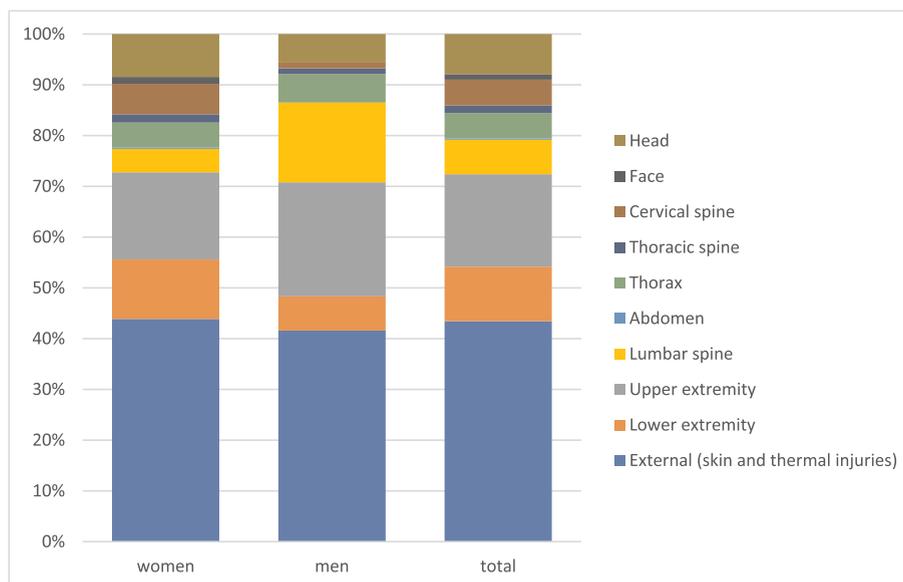


Fig. 1. Distribution of injured body regions for all injuries ($n = 456$) among female and male passengers injured while falling due to acceleration or braking while standing on a moving bus.

Table 5
Percentage of MAIS severity categorised into women and men.

MAIS	Female users		Male users		Total	
	n	%	n	%	N	%
1	179	70%	36	59%	215	68%
2	68	27%	22	36%	90	29%
3	8	3%	2	3%	10	3%
4	–	–	1	2%	1	0%
Total	255		61		316	100%

admitted in hospital and five of these patients stayed in hospital four days or longer. Those who were admitted in hospital were mostly female users (5 out of 6) aged 75 + and sustained an skeletal injury of AIS = 3 ($n = 5$) in the pelvis region or the limbs. One sustained an internal injury in the head of AIS = 3. Those who were not admitted ($n = 4$), although they sustained a MAIS 3 injury, were mostly younger passenger compared to those who were admitted, aged on average 65 years-old ($n = 3$). Two of them sustained a lumbar spine injury of AIS = 3.

There was one passenger who sustained an injury of MAIS 4. The passenger was a male user aged 76 who stayed in hospital more than 30 days. The passenger sustained injuries of type internal organs in the thorax (AIS = 4) and skeletal in the head (AIS = 3). The results in Table 6 show that as age increases the number and the severity of injured passengers increases as well.

Fig. 2 shows that for acceleration manoeuvres, *boarding* is the most common passenger condition resulting in an injury of MAIS 1 or MAIS 2 + severity, virtually equally distributed between the most involved group, 65+. On the other hand, for hard braking manoeuvres, most of the falling events are related to the *travelling* passenger condition resulting in most of the cases in MAIS 1 injury severity. Moreover, the most afflicted age group is the 25–64 age group, (i.e., passengers in the active working age group).

Table 6
Number of MAIS severity scores categorised by age group.

MAIS	Age ≤ 15	Age 16–24	Age 25–64	Age 65 +
1	10	21	90	94
2	-	3	26	61
3	-	-	3	7
4	-	-	-	1
Total	10	24	119	163

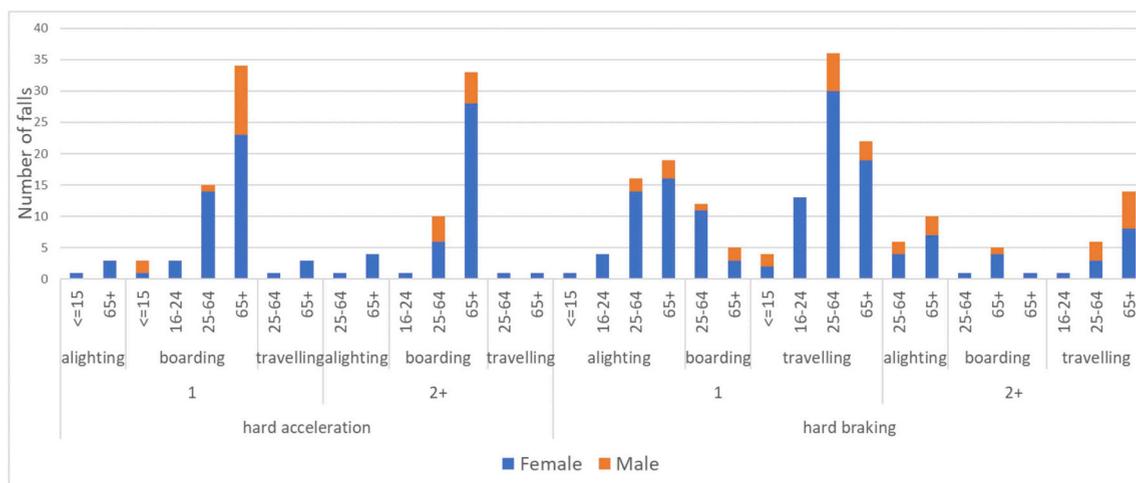


Fig. 2. Number of falls for female and male users categorised by age group, MAIS, driver manoeuvre and passenger condition.

4.4. Hospitalised and care days

The total number of passengers who were admitted in hospital was 42 out of 316 cases (13%). From this group of passengers, 16 were hospitalised up to one day, 21 passengers stayed in the hospital between two and seven days, and five passengers stayed in the hospital longer than seven days. The age distribution showed that passengers belonging to the 65 + age group, represented 71% of the hospitalised passengers. The results also showed that most of the hospitalised passengers fell after *boarding* (n = 18) and while *travelling* (n = 14), whereas few of the hospitalised passengers fell before *alighting* (n = 5). No one aged 15 years-old or younger was admitted in hospital. See Table 7.

Table 8 shows that most of the hospitalised passengers had sustained an injury of category MAIS = 2+ (> 70%). The most commonly injured body region was the abdomen/pelvis (n = 11), followed by head/face (n = 10).

4.5. Common situations involving a fall during hard acceleration or braking manoeuvres

The event chain description in STRADA can potentially clarify some circumstances which led to a fall which are listed below.

Table 7
Care days, passenger condition, and age groups.

Care days	Age group			Total
	16–24	25–64	65 +	
< = 1	0	9	7	16 (38%)
2 to 7	1	2	18	21 (50%)
> 7	0	0	5	5 (12%)
Total	1	11 (26%)	30 (71%)	42
Passenger condition				Total
Alighting	0	0	5	5 (12%)
Boarding	0	3	15	18 (43%)
Travelling	1	5	8	14 (33%)
Unknown	0	3	2	5 (12%)
Total	1	11	30	42

Table 8
Hospitalised passengers, injury distribution, and MAIS.

	Abdomen/Pelvis	Limbs upper	Head/Face	Limbs lower	Lumbar spine	Torso	Shoulders	Spine/Back	Neck	Total
MAIS = 1	4	0	5	0	0	1	0	1	1	12
MAIS = 2	4	5	4	3	3	1	2	1	0	23
MAIS = 3	3	1	1	1	0	0	0	0	0	6
MAIS = 4	0	0	0	0	0	1	0	0	0	1

- Sudden opposing manoeuvres such as a hard acceleration followed immediately by a hard braking manoeuvre (n = 13) and vice versa, i.e., a hard braking manoeuvre followed by a hard acceleration (n = 3).
- Bus driver missed a stop (n = 11) resulting in the standing passenger losing balance after warning the driver who reacted with a sudden braking manoeuvre.
- Several braking manoeuvres in a short period of time (e.g., two to three times) which led to standing passengers falling (n = 4) due to they were still compensating for the first manoeuvre when the second or third braking manoeuvre occurred.
- Bus driver suddenly braking immediately after swerving from bus stop (n = 3) to wait for more passengers.

5. Discussion

Previous studies on falls due to non-collision events on buses have found that sudden braking manoeuvres were the most frequent reason for standing passengers falling (Björnstig et al., 2005; Kirk et al., 2003; Halpern et al., 2005; Kendrick et al., 2015). However, those studies do not specify driver manoeuvres and passenger conditions at the time the fall events occurred. This study aimed to further investigate driver manoeuvre in relation to passenger condition, (i.e., standing after *boarding*, standing before *alighting* or standing while *travelling* in falling events on buses). The main finding of this study is that different mechanisms and factors may be involved based on prevailing driver manoeuvres and passenger conditions at the time of a fall event.

The risk of falling onboard a public transport vehicle has been investigated by Elvik (2019) and estimated around 0.3–0.5 per million passenger kilometres. However, it is important to establish whether female users of public transport, especially anyone aged 65+, have a higher risk of being injured in non-collision incidents. Unfortunately, this type of data is not easily available. Based on travel survey data for all PT systems, there is evidence to support that female users travel slightly longer distances (i.e., higher exposure) than their male counterparts in Sweden (on average 2 km longer), at least up to the age of 74 (RVU, 2017).

Our results are in line with the literature reporting elderly female users as most commonly injured in non-collision falling events on buses (Björnstig et al., 2005; Kirk et al., 2003; Halpern et al., 2005; Kendrick et al., 2015). Moreover, our results indicate that female involvement is also high in younger age groups (< = 15, 16–24, 25–64), compared to their male counterparts. The higher female involvement for all age groups in falling events on buses may partially be explained by the slightly higher exposure to public transport according to Swedish national statistics. However, the high female involvement for all age groups found in this study may also indicate that other factors needing to be address may prevail, (e.g., biomechanical differences to maintain balance). Schubert et al. (2017) found that increased age is a factor resulting in lower acceleration threshold values for maintaining balance and Karekla and Tyler (2018) found in a gait analysis study with passengers ‘walking’ on a moving bus that older female participants needed more time with their feet on the ground to compensate for acceleration perturbances. Thus, gender differences for different age groups might be important to investigate further while standing on a moving bus subject to hard acceleration or hard braking manoeuvres.

Furthermore, our results reveal that non-collision falling events are significantly influenced by bus drivers. In line with the literature, most of the falling events were connected to hard braking manoeuvres (Halpern et al., 2005). Our findings indicate that braking manoeuvres afflicting passengers are related to falling events during the passenger conditions *travelling* or *alighting*. Whereas, hard acceleration manoeuvres are related to passenger falling events almost exclusively in the passenger condition *boarding*. These results may imply that the characteristics of bus passenger falling events differ and should therefore be studied separately. For example, falling events due to hard acceleration is specific for *boarding* situations involving the oldest age group. Whereas, falls due to hard braking manoeuvres are specific for *travelling* and *alighting* involving the 25–64 years-old age group most frequently. With an overrepresentation in both manoeuvres of female users.

From a human factors perspective, hard braking manoeuvres, (e.g., emergency braking), are generally unexpected as well as required to avoid a collision due to traffic conditions at the time of the falling event. For example, when it was possible to identify the obstacle, most of the hard braking manoeuvres was related to avoid a collision with another vehicle (n = 29), followed by interference by pedestrians and cyclists (n = 18), and to avoid a collision with a wild animal (n = 4). Thus, braking manoeuvres are likely to be triggered by factors such as traffic conditions, interference by other road users and possibly driver distraction. Conversely, attributing hard acceleration manoeuvres to traffic conditions might be much more challenging as fleet management strategies and driving behaviour may be behind such manoeuvres. For example, tight bus schedules or delay allowances might influence bus driver behaviour, which may compel them to swerve from a bus stop without waiting for all passengers to be seated. The data show.

That out of 120 falling events under acceleration manoeuvres, 99 passengers fell after boarding the bus whilst attempting to get seated and mostly involving the oldest age group. The literature highlights that buses show higher acceleration levels compared to other PT systems (Schubert et al., 2017; Graaf and van Weperen, 1997), surpassing largely the thresholds to maintain balance (Graaf and van Weperen, 1997). Driving behaviour can also explain hard acceleration manoeuvres. For example, Kottenhoff and Sundström

(2011) found that the driving style of 10% of bus drivers made the journey uncomfortable for passengers in a study of bus riding comfort in Stockholm. Palacio et al. (2009) advocates that bus drivers should be made aware of that hard acceleration quickly, followed by a sudden deceleration can result in severe injuries.

One group of passengers who might be more vulnerable to falling events is the group of elderly passengers taking longer for them to get seated (Schubert et al., 2017) and even longer for those passengers accommodating a walking frame. This group of passengers may present special conditions which may need to be addressed. It is important for elderly passengers to get seated as quickly as possible (Schubert et al., 2017) or to shorten the time for elderly passengers to get seated. Elderly passengers may not need to scan their travel cards before sitting down. For example, they can get onboard through the bus middle door and directly seat down on the reserved places and scan their travel cards in a special pay scanner which may be placed in a different location allowing them to pay after properly seated. In the dataset, 24 passengers reported that they used a walking frame at the time of the falling event (n = 18 female users). More importantly, 19 of the 24 passengers fell after boarding during a hard acceleration manoeuvre whilst three fell before alighting. Therefore, the deterioration of the travel experience can be compromised if corrected actions are not taken, specially for elderly passengers with special needs.

It is also important to note that bus drivers should be made aware of that sudden braking manoeuvres due to passengers arriving late and attempting to board or missed bus stops may result in standing passengers falling. Additionally, passengers should be made aware of that warning the driver to stop may result in a hard braking manoeuvre and possibly to a fall event, as well.

6. Conclusions

Driver manoeuvres and passenger conditions are important characteristics impacting the mechanisms of falling on buses and possibly impacting injury severity. For acceleration manoeuvres, falling events while *boarding* are the most commonly reported cases, whereas for braking manoeuvres *travelling* and *alighting* are most common. These findings may indicate that acceleration and braking manoeuvres on buses should be studied separately. For example, age can be used as a factor in acceleration manoeuvres as it makes longer the process to get seated, while threshold values for retaining balance during braking manoeuvres may be dependent on gender.

Hard braking manoeuvres may be connected to collision avoidance manoeuvres and possibly driver distraction. However, hard acceleration manoeuvres may be more linked to fleet management strategies (e.g., bus schedules) and driving behaviour. Under acceleration manoeuvres, elderly passengers are overrepresented due to the time it takes to get seated. And even longer if the passenger accommodates a walking frame. Therefore, new payment strategies may be introduced to shorten the time to get seated for passengers with reduced mobility who may scan their travel cards already seated in special located pay scanners. Furthermore, bus driver training programmes may also be introduced that aim for users with special requirements (e.g., elderly users after boarding not seated, passengers with walking frames) and therefore avoid risky driving manoeuvres. Palacio et al. (2009) advocates that bus drivers should be aware of that hard acceleration followed by sudden braking may result in severe fall injuries.

An interesting research direction is to further investigate hard braking manoeuvres which can give light into whether these manoeuvres responde to traffic conditions (e.g., collision avoidance due to interference of other road users), driver distraction or driving style.

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