Fall detection for a side-impact airbag in cycling

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ABSTRACT

Many accidents among elderly on e-bikes happen at slow speed, while stopping and starting, and during mounting and dismounting. An airbag could protect the cyclist in a fall against hip or pelvis fracture. Such a hip-airbag, together with a dedicated fall detection algorithm, has been developed by WOLK, to handle activities in daily living for elderly on foot, like during walking, sitting down, standing up, etc. We investigated experimentally if such an airbag could be applied to catch (dis)mounting falls in cycling. First, in a control experiment it was demonstrated that there were no false positives generated during normal cycling. Next, with eight participants a total of 99 bicycle falls and 142 walking falls during (dis)mounting were recorded and analysed. The results show that the percentage of falls detected by the WOLK fall detection algorithm in cycling falls as compared to walking falls were similar, both around 73%. Clearly, the fall detection algorithm of the WOLK hip airbag works as good in cycling as in walking.

Keywords: cycling falls, side impact airbag, fall detection, experimental validation, elderly.

1 INTRODUCTION

In the Netherlands almost a quarter of the Dutch population, about 24%, cycles every day, out of which 17% over the age of 65 (Harms and Kansen 2018). Each year at least 12000 (now increasing) elderly cyclists in the Netherlands meet with a single bicycle crash accidents and are more or less severely injured (Twisk, Bos et al. 2017). In general, the risk of injury for the elderly cyclists is about three times higher than an average bicyclist and for elderly cyclists aged 75 to 84 years, it is about six times higher (Ekman, Welander et al. 2001). During cycling, there are plenty of causes that can lead to various single bicycle crash types. However, the most common E-bike single bicycle crash type is falling during (dis)mounting the bicycle (20-25%) (Dubbeldam, Baten et al. 2017), cycling at low speeds (16%) (Schepers and Wolt 2012), cycling at high speeds (12%) (Schepers and Wolt 2012) and difficulty in maneuvering (11-13%) (Schepers and Wolt 2012). Possible reasons for higher fall risks during (dis)mounting the bicycle and low cycling speed could be the physical weakness of the elderly (Schepers and Wolt 2012), difficulty in maintaining balance at low speeds (Kooijman, Meijaard et al. 2011, Moore, Kooijman et al. 2011) and/or the use of a stepping technique while (dis)mounting the bicycle which is different as compared to the young cyclist (Dubbeldam, Baten et al. 2017). Protective wear could prevent injuries in these falls. We are already familiar with the usage and success of helmets, which can protect the head from injuries due to large impacts. However, another common injury among the elderly in a fall is a hip injury. The usage of a hip-airbag could prevent these injuries. Such a hip-airbag has been developed by WOLK ("WOLK") as a protective wear to handle activities of daily living (ADLs) for elderly on foot, like walking, sitting down, standing up, etc., see Figure 1.

Figure 1. Left: WOLK hip-airbag. Right: WOLK airbag as worn by the user between under- and visible wear ("WOLK").

Although developed for walking, one could also wear the hip airbag during more sportive activities, like cycling, ice skating or playing tennis, based on the inputs of WOLK users. Therefore, the goal of this research work is to evaluate the performance of the fall detection algorithm of the WOLK hip airbag during cycling via an experimental setup. This brings us to the research questions: How well is the current fall-detection algorithm of the WOLK hip airbag able to detect falls in cycling at slow to zero speed in (dis)mounting (true positives) and how sensitive is the current algorithm to activate during cycling related activities that are not falls (false positives)?

After this gentle introduction we present the methods used with the description of the experimental setups. In the next section the results are presented and discussed. We end with some conclusions and directions towards future research.

2 METHODS

The performance of the fall detection algorithm of the WOLK hip airbag has been tested in an experimental setup for (dis)mounting in cycling. In this method section we start by identifying which (dis)mounting is commonly used by elderly. Next we describe the experimental setup.

2.1 (dis)mounting techniques in cycling

Most elderly use the stepping technique while mounting and dismounting the bicycle (Twisk, Platteel et al. 2017). This type of technique in particular is considered to be riskier as the older cyclists tend to have a higher thigh acceleration as compared to the younger cyclists. The major difference between mounting and dismounting phase can be witnessed by which foot was placed or removed on the pedal first. In a study conducted by Paul T.C. Straathof at Roessingh Research and Development (Straathof 2014), it is demonstrated that during mounting, 70% of the younger cyclists lifted their right foot through the frame and placed it on the right pedal while 80% of the older cyclists placed their left foot on the left pedal which was on the same side as the bicycle as they were positioned. It is further emphasised that the choice of mounting/dismounting method and physical abilities of the individual had an influence in bicycle accidents (Straathof 2014). The stepping technique used by the elderly can be further categorised into two types of mounting and dismounting phases such as Type 1 (dis)mounting Phase and Type 2 (dis)mounting Phase. The major difference between Type 1 and Type 2 is the placement of the right foot on the right pedal either through or over the frame, see Figure 2.

Type 1 Type 2

Figure 2. Two bicycle mounting techniques from the left, with the left stance foot on the left pedal: Type1, where the right swing foot is moved through the frame to the right. Type 2: where the right swing foot is moved over the frame to the right (Straathof 2014).

Type 1 Mounting Phase can be described as placing the left foot on the left pedal first, as the right foot pushes on the ground through steps to gain speed, while eventually bringing the right foot **through the frame** onto the right pedal. Type 1 Dismounting Phase can be described as applying light brakes while getting off the saddle with the right foot through the frame on the ground and the bicycle is at a halt completely. This type of (dis)mounting method is usually preferred by female elderly cyclists. On the other hand, Type 2 Mounting Phase can be described as placing the left foot on the left pedal first, as the right foot pushes on the ground through steps to gain speed, while eventually bringing the right foot **over the frame** onto the right pedal. Type 2 Dismounting Phase can be described as applying light brakes while getting off the saddle with the right foot over the frame on the ground and the bicycle is at a halt completely. This type of (dis)mounting method is usually preferred by male elderly cyclists. Based on the results obtained by Paul T.C. Straathof at Roessingh Research and Development (Straathof 2014), using 95% confidence interval, it can be estimated that for the sampled population, the proportion of elderly cyclists who choose either Type 1 or Type 2 Mounting phase lies somewhere between 68.67% and 94.97% of the true population. Also, it can be estimated that for the sampled population, the proportion of elderly cyclists who choose either Type 1 or Type 2 Dismounting phase lies somewhere between 32.68% and 67.32% of the true population. As these values were statistically significant and reliable, we performed both Type 1 and Type 2 (dis)mounting technique in our experiments.

2.2 Experimental setup

The experimental setup included three stages of equal dimensions 200x100x30 cm positioned in between two mattresses of equal dimensions 300x200x30 cm in the corridors of the WOLK office building, see Figure 3. The stages acted as the runway for cycling and the mattresses prevented any injuries from the fall. The bicycle was a standard Dutch e-bike with a mid-engine and the battery on the rear rack. The bicycle was covered in bubble wrap and foam rubber to prevent any injuries to the participant during the fall.

Figure 3. Experimental setup with four sequential moments during a typical fall. On either side of the runway is a soft mattress of 300x200x30 cm to catch the fall.

In this study two type of experiments were conducted, Control and Pilot. Both types were performed by two groups of participants namely, Group 1 and Group 2. Before the start of the experiment, all participants were made to wear the WOLK hip-airbag over their undergarments. The participants were also instructed on the experimental strategy using a manual and catalogue. A catalogue was designed for visual representation of the Type 1 and Type 2 (dis)mounting techniques and their individual actions. All experiments were recorded using a camera setup. The measured data was from the inertial measurement unit (IMU) which is integrated in the WOLK airbag and supplies the necessary data for the fall detection algorithm. Upon completion of the experiments, the IMU data from WOLK hip-airbag was run through an emulator to generate motion detection features and the fall detection time. This data was then run through a Matlab code to identify the impact time from the plots of vertical velocity. With the impact time and detection time, other variables such as acceleration, vertical distance, roll angle prediction and roll angle plots were generated and analysed further.

2.2.1 Input and output data

The input and output data for the testing and verification of the fall-detection algorithm of the WOLK hip airbag in cycling are presented in Table 1. A total of eight participants were divided into two groups, Group 1 and Group 2, for the separate verification of the left and right sensors placed in WOLK hip-airbag. The output data that is used to quantify the performance are: vertical velocity of the fall, detection time of the fall, impact time of the fall and lead time, based on graphical analysis. Based on the vertical velocity, the type of falls are further classified as: VERY SOFT, SOFT, HARD and VERY HARD.

Table 1. Input and output data of the experiments.

INPUT DATA		OUTPUT DATA	
Number of Participants	Group 1: 4 participants, Left falling	Vertical Velocity (downwards, m/s)	1 - 1.5, VERY SOFT fall
	Group 2: 4 participants, Right falling		1.5 - 2, SOFT fall
Height range of the participants	173 cm to 203 cm		2 - 2.5, HARD fall
Type of bicycle used	E-bike		> 2.5, VERY HARD fall
Speed of the E-bike	5km/hr to 25km/hr	Lead Time = Impact time - Detection time (ms)	> 75

2.2.2 Control experiment

The control experiment included collecting all IMU data from WOLK for type 1 and type 2 (dis)mounting phases in a regular biking state (with no falls) for all participants. The aim of this experiment is to investigate any false positives in the fall-detection algorithm of WOLK. Participants of Group 1 performed the experiment by cycling around the corridors inside the WOLK office building, with pillars acting as obstacles on the road to mimic the real-life setting. While, Participants of Group 2 performed the experiment by cycling one lap outside in a real-life setting, around the WOLK office building. Therefore, as seen in Table 2, in total for control experiment, the number of bike actions performed by each participant for both mounting and dismounting phase is 2.

Table 2. Number of bike actions per bike phase for each type of experiment.

CONTROL EXPERIMENTS - FOR NO FALLS				
TYPE	MOUNTING PHASE	DISMOUNTING PHASE	SUBTOTAL NO. OF BIKE ACTIONS	TOTAL NO. OF BIKE ACTIONS
	NO. OF BIKE ACTIONS PER TYPE			
1	1	1	1	2
2	1	1	1	
PILOT EXPERIMENTS - FOR FALLS				
TYPE	MOUNTING PHASE	DISMOUNTING PHASE	SUBTOTAL NO. OF BIKE ACTIONS	TOTAL NO. OF BIKE ACTIONS
	NO. OF BIKE ACTIONS PER TYPE			
1	4	3	7	14
2	4	3	7	
TOTAL NO. OF ACTIONS TO BE PERFORMED BY EACH PARTICIPANT				16

2.2.3 Pilot experiment

The pilot experiment included collecting all IMU data from WOLK for type 1 and type 2 (dis)mounting phases in the fall state for all participants and comparing it with walking falls. The aim of this experiment is to observe and compare how WOLK responds to the different bike actions in different bike phases and analyse the collected data with the reference walking falls. Both groups of participants were made to perform the various bike actions as shown on the catalogue. For the walking falls, a pre-designed catalogue by WOLK is used. Therefore, as seen in Table 2, in total for pilot experiment, the number of bike actions performed by each participant for both mounting and dismounting phase is 14 while for walking fall actions is 18.

3 RESULTS AND DISCUSSION

An example of a fall is shown in Figure 1, and the corresponding fall data on the vertical velocity, the roll angle prediction and the time of fall detection and impact are shown in Figure 4.

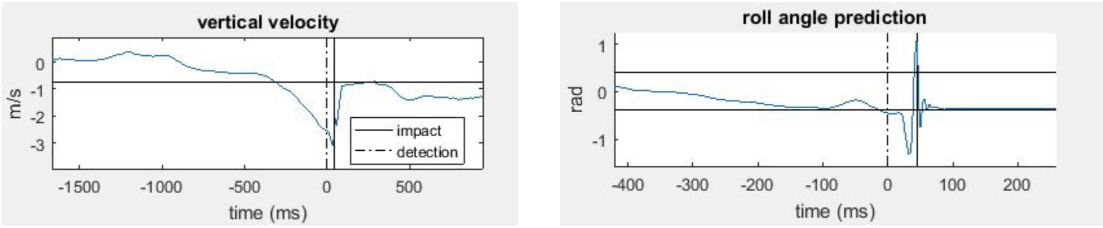

Figure 4. Vertical velocity and roll angle prediction as a function of time for a fall as shown in Figure 3, together with impact time and fall detection time.

For the control experiment, no false positives in the fall-detection algorithm of WOLK were identified for all participants, throughout the regular biking phase. For the pilot experiment, the total number of falls recorded was 241 with 99 biking falls and 142 walking falls. All the falls were further categorised into three groups: Falls detected (for lead times above 75ms); Falls detected late (for lead times below 75ms) and; Falls not detected (for negative or nil lead times). As shown in Figure 5, the percentage of falls detected by the WOLK algorithm for bicycle falls as compared to walking falls was similar. However, the remaining percentages differed in that bicycle falls detected late were more and bicycle falls not detected were less than those in walking.

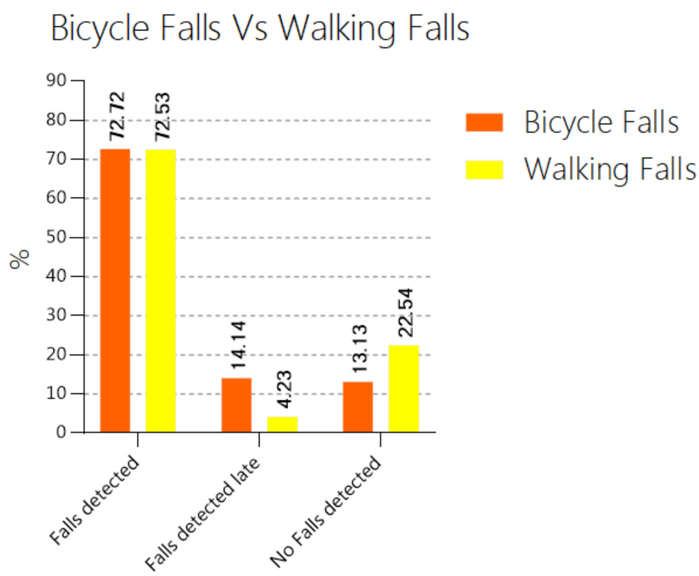

Figure 5. Results for bicycle falls and walking falls in percentage. The total number of experiments was for cycling falls n=99, and for walking falls n=142.

Based on a statistical analysis on the measured data, it can be estimated, with 95% confidence, that for the sampled proportion, bicycle falls will be detected (on time and late) for 80.22% to 93.52% of the real population. Concurrently, it can also be estimated with 95% confidence that for the sampled proportion, bicycle falls will not be detected for 6.48% to 19.78% of the real population. Clearly, the fall detection algorithm of the WOLK hip airbag works as good in cycling as in walking.

4 CONCLUSIONS

The WOLK fall detection algorithm has been tested and verified during the dismounting and mounting phase on an e-bike where we conclude that that the detection algorithm works as good in cycling as it works in walking. It can be estimated, with 95% confidence, that for the sampled proportion, bicycle falls will be detected (on time and late) for 80.22% to 93.52% of the real population. Concurrently, it can also be estimated with 95% confidence that for the sampled proportion, bicycle falls will not be detected for 6.48% to 19.78% of the real population. Clearly, the fall detection algorithm of the WOLK hip airbag works as good in cycling as in walking.

However, there is room for improvement. Future work could be directed towards investigating how speed of the E-bike with a longer runway for (dis)mounting could affect the falls/impact, how using the knee as a support to stop a fall from the bicycle hampers detection and understanding why it is happening, and understanding the body dynamics during bicycle falls and the relation between the height of the person and the fall from the bicycle.

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