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Development of a safe cycling test protocol to evaluate potential fall risk situations for elderly cyclists

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SUMMARY

Elderly cyclists have a high risk of injury due to a fall with their bicycle in single bicycle accidents where no other road users are directly involved. The aim of this study was to explore critical cycling situations for elderly cyclists, develop a cycling test protocol and evaluate the usability of an ambulatory measurement system to assess cycling kinematics.

A literature study was performed to define the most frequent cycling accidents in which elderly cyclists are involved. The causes of the cycling accidents were evaluated, transformed into cycling actions and included in a cycling test protocol. The cycling kinematics of the bicycle-cyclist system were assessed by means of 24 inertial magnetic sensor units.

Frequent causes for the single-accidents with elderly cyclists were getting on or off the bicycle, ground irregularities, slipping and giving way. Furthermore, most accidents occurred while standing still or at slow speed (5 km/h). The test protocol included normal and slow straight cycling with getting on or off the bicycle, cornering, looking behind and obstacle crossing.

Getting on the bicycle coincided with a peak in lateral acceleration of the bicycle frame, a peak in upper body angular velocity and an increase in upper leg orientation to step over the frame. Our results furthermore showed an increase in maximum steering angular velocity with reduced cycling speed or as consequence of head turning while cycling.

In conclusion, critical cycling situations can be transformed into a relatively simple and safe cycling test protocol to study cycling behavior. The IMU's can be used to successfully explore variations in cycling kinematics and evaluate cycling stability.

INTRODUCTION

Cycling is a healthy activity and a much used mode of transportation in many countries. Regarding the elderly population, cycling keeps elderly people mobile and contributes to their independence and quality of life [1]. In The Netherlands, bicycle usage is increasing in popularity in the elderly population, among others due to the introduction of the electrical bicycles. However, elderly cyclists are frequently injured in cycling accidents: in The Netherlands 15000 elderly cyclists (55+) require medical attention each year and that number is increasing [2]. Compared to younger cyclists, the risk of injury increases up to a factor 6 from the age of 55 years [2].

The causes of the accidents with elderly cyclists have been studied and 75% of the accidents are so-called single-accidents where no other road user is directly involved [2]. So far little is known about the underlying mechanisms, such as physical or cognitive degeneration of the elderly cyclist, that result in the cycling instability inevitably related to the bicycle falls. A better understanding of the differences in cycling kinematic behavior between young and elderly cyclists and the underlying mechanisms could provide guidelines for bicycle design and improve cycling stability and safety.

The aim of this study was to develop a safe cycling test protocol with cycling activities which represent potential fall risk situations and explore the use of ambulatory movement analysis technologies to study cycling kinematics outdoors.

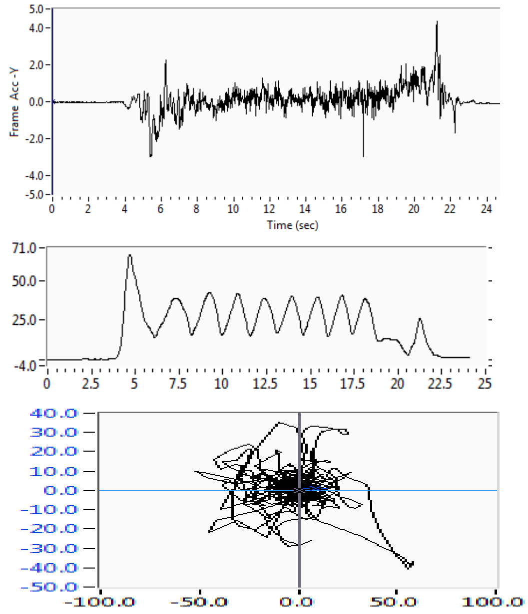
METHODS

A literature study was performed to determine the most frequent causes for single bicycle accidents with elderly subjects. Since such accidents are infrastructure- and country-specific, our focus was on the Dutch accident analyses. The cycling situations with a high risk for accidents and injury were defined and transformed to representative cycling activities and included in a cycling test protocol.

Inertial Magnetic Sensor Units (IMU's) consist of an accelerometer, gyroscope and magneto sensor with which 3-dimensional human movement can be assessed. So far, IMU's are successfully used for ambulatory movement analysis indoors [3-5]. IMU's however make it possible to observe the occupants outdoors and hence are increasingly used to study other human movements such as darting or cycling in real life [6,7].

In this study we applied 24 wired IMU's (Xsens, Enschede, The Netherlands): 1 on the frame and 1 on the handlebar of the bicycle; 22 sensors on the body segments of the cyclist. The IMU output signals are recorded on a laptop and our software program FUSION, written in LABVIEW, is used to assess the orientations and accelerations of the bicycle and human body segments in the inertial reference frame or with respect to each other. In this study, we focus on the bicycle frame accelerations as well as the frame, the steering and upper body angular velocity. In the following, the z-axis is the vertical, the x-axis is the heading and the y-axis is the lateral direction.

One female participant (39 years) performed the cycling test protocol to test the protocol and usability of the IMU's in determining cycling kinematics.



a.

b.

c.

Figure 1: a. Lateral acceleration of the frame and b. Upper leg orientation as function of time; c. Upper body angular velocity in x- and z- direction. During: getting on, normal straight cycling, and getting off.

RESULTS AND DISCUSSION

Frequent causes for the single-accidents with elderly cyclists were getting on or off the bicycle, ground irregularities, slipping and giving way [2,8,9]. Furthermore, most accident occurred while standing still or at slow speed (5 km/h) [2]. Slipping and giving way were considered too dangerous to be included in the test protocol. Giving way, a sudden maneuvering, was replaced by the more controlled cornering and cycling while looking behind. The finally developed cycling test protocol consists of the following cycling actions:

- Normal straight cycling, including getting on/off the bike
- Slow straight cycling
- Cycling and looking behind
- Cornering
- Obstacle crossing

In figure 1 the effects of getting on the bicycle are shown. The bicycle frame lateral acceleration, the steer angle and the upper body angular velocity all peak during getting on the bicycle.

The problems of elderly cyclists while getting on or off the bicycle are bot yet understood. The above studied kinematic parameters could be used to explore the issues of elderly cyclists with getting on the bicycle such as stiff hips limiting upper leg orientation, which results in a higher risk to hook the foot behind the frame; or insufficient upper body lean to compensate for a heavy electric bicycle.

Figure 2 shows the increase in steering angular velocity with increasing task difficulty: normal cycling, cycling at low speed and turning head to look behind while cycling. Moore et al. found a similar change in steer behavior for lower cycling speeds [10]. The turning of the head during cycling results in loss of sense of direction. This loss of the heading directly results in significantly more steering activity.

CONCLUSIONS

Several critical cycling situations could be identified for elderly cyclists and transformed into a safe cycling test protocol. The IMU's were successfully able to explore differences in cycling kinematics between various cycling activities. As a next step, the cycling test protocol will be performed with young (18-40 years) and elderly (65+) cyclists to assess differences in cycling behavior.

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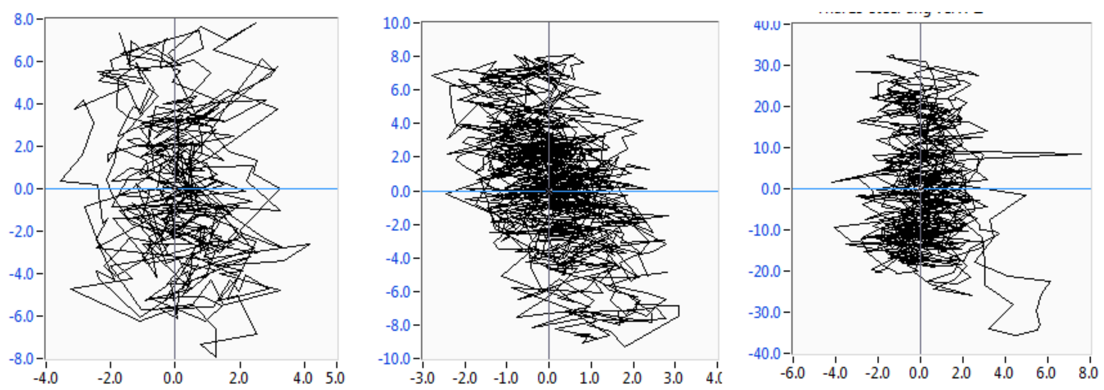

Figure 2: Steering angular velocity with respect to bicycle frame in x- (heading) and z-(vertical) direction at a. normal cycling, b. slow cycling, c. cycling while turning head 3 times**.**