Preliminary results from a field experiment on e-bike safety: speed choice and mental workload for middle-aged and elderly cyclists

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ABSTRACT

To study the safety of e-bikes for the elderly, an experimental field study was conducted, using instrumented bicycles and comparing two age groups: older cyclists, n = 29, mean age = 70, SD = 4.2 and middle-aged cyclists, n = 29, mean age = 38, SD = 4.3. All were regular cyclists. They rode a fixed route with a length of about 3.5 km: once on an instrumented e-bike and once on an instrumented conventional bike, in counterbalanced order. Measures were taken on heart rate, mental workload, and geographical position (GPS), balance and riding speed. This paper only reports a subset of the results namely the main findings on speed and mental workload. As predicted, both age groups rode significantly faster on an e-bike than on a conventional bike. This difference was greatest on the straight sections, but only small in bends. In all situations (turn to the left, and straight) older cyclists rode slower than middle-aged bicyclists, both on an e-bike and a conventional bicycle. In fact, the speed of elderly on e-bikes did not differ from that of middle-aged participants on conventional bikes. As expected, mental workload was higher in complex situations (left turns), than in simple ones (straight sections). Mental workload in complex situations were even higher for the elderly. But no difference was found for bicycle type. These results suggest that cyclists slow down their speeds in complex traffic situations, and that this pattern does not differ between conventional or e-bikes, nor between the two age groups. It is still too early to draw conclusions about the safety of e-bikes. Additional analyses will be carried out to assess the robustness of these conclusions.

Keywords: e-bike, older cyclists, field study, instrumented bicycles, safety, speed, mental workload
1. INTRODUCTION

The last decade, the number of seriously injured cyclists in the Netherlands has increased considerably, especially among the elderly [1, 2]. During that same period the number of e-bikes has increased. According to Dutch law, an e-bike is a bicycle if it provides support up to a speed of 25 km/h and if it only provides that support if the rider is pedalling. Nowadays 1 out of 20 Dutch inhabitants are in possession of an e-bike, which amounts to a total of about 1 million e-bikes [3]. E-bikes account for 10% of the total distance travelled by bicycle in the Netherlands [3] and are mostly used by the elderly [4]. There are concerns about the safety of e-bikes., Studies show that the number of injured cyclists who seeks treatment in an emergency room because of a crash with an e-bike has been increasing [5]. Possible explanations for this increase are the rising numbers of e-bikes on the road, its popularity among the vulnerable elderly, the possible negative influence of its higher weight (50%) on cycle performance, and the presumed higher cycling speeds [3, 5]. So far, however, little is known about the effects of e-bikes on speed choice, balance and vehicle handling in traffic situations. Such a deeper understanding is required for optimising the designs of e-bikes and road infra-structure, so that these are safe for e-bikers of different age groups. The objective of this study was to assess the impact of e-bikes on cycling behavior of cyclists of different age groups with an emphasis on safety, under controlled conditions in real traffic. This paper reports the findings on riding speed and mental workload.

Speed is a known contributor to crashes and crash severity. Little is known about the difference in actual riding speeds of conventional cyclists and e-bike riders. The latest report on cycle speed of conventional cyclists dates back to 1987 and reports an average speed of about 16 km/h [1]. A recent study on e-bike speeds, used information from the e-bike computers, and estimated a cruising speed of a little less than 20 km/h [2]. Because of higher speeds being associated with a higher crash risk and injury severity [3], information about the actual riding speed of e-bikes in comparison to conventional bicycles is extremely relevant for safety [4]. Further, the ability of e-bikes to accelerate faster in combination with higher speeds may also be a contributing factor to general changes in cycling behavior. In China, for instance, e-bike riders violated traffic lights more frequently than conventional cyclists. [5].

Another aspect that is of concern to the safety of e-bikes is their weight. E-bikes are about 9 kg heavier than conventional bicycles. Further, the center of gravity is situated at a higher location than for a conventional bicycle. This, because of the position of the electric motor fitted in one of the wheels and the battery underneath luggage carrier [2]. These characteristics may affect the handling of the bicycle in terms of stability during the ride, but also while mounting and dismounting the bicycle.

Recent studies show that e-bike users travel larger distances than conventional cyclists. For cyclists over 60 years of age this is even double the distance [2]. Little is known about the rider population and the motives for using e-bikes. However, it is most likely that cyclists who have problems handling conventional bicycles, for instance because of loss of muscle strength or cyclists who fancy longer cycle trips may turn to e-bikes. This may be the reason that e-bikes are so popular among the elderly.

Despite concerns about the safety of e-bikes, to date only few studies have assessed e-bike crash risk, its relationship with cycling behavior and the extent to which the use of these bicycles may contribute to the rising numbers of serious injuries among cyclists [6]. Data obtained from surveys among cyclists who sought treatment in an Emergency Room because of a cycle crash, confirm that e-bike related injuries are on the rise [7]. However, this rise may just reflect
the increasing share of e-bikes on Dutch roads. These surveys further showed that e-bike riders reported more frequently to have fallen while mounting or dismounting their bicycle than conventional cyclists. This may be related to the e-bike’s higher weight and higher point of gravity. In contrast to expectation, ‘too high a riding speed’ as cause of a crash did not differ between the two cycle types. A related study succeeded in estimating the actual injury risk – the number of injured cyclists by distance travelled – by using mileage data from e-bike computers and combining that with the injury data [2]. With this method, the injury risk of e-bikers under 75 of age was shown to be a little lower than that of conventional cyclists of that age. However, for cyclists over the age of 75, injury risk of e-bikes was double that of users of conventional bicycles [2]. This pattern of results resembles findings from research in the early Nineties concerning the safety of Spartamets. The Spartamet resembles the current e-bike apart from the engine. The e-bike is powered by an electric engine, whereas the Spartamet is powered by a combustion engine. This study showed that the injury risk (injuries per distance) for the age group of 25 to 49 year olds, of a Spartamet did not differ from that of bicycles. But, similar to the e-bike, for the age group of 50 and older the injury risk of a Spartamet was double that of a bicycle [8].

Crash studies do not address the cause of these higher injury rates of e-bikes. Is vehicle handling an issue because of its heavier weight and other vehicle characteristics? Does the infrastructure create a problem because of the higher speeds? Are cyclists sufficiently adapting their speeds to the traffic conditions and to their limitations? To answer these questions, more insight is needed in the cycling behavior in relation to the traffic conditions.

1.1. Speed and mental workload: approach and hypotheses

To study the behavior of cyclists on e-bikes, we conducted an experimental field study, in real traffic. In the experiment, participants rode a fixed route including several intersections and slopes[9] once on an e-bike and once a conventional bike. Both bicycles were equipped with camera, sensors and a laptop to record the data. In addition to the fixed route, participants performed several cycle related tasks under instruction of the leader of the experiment, such as mounting and dismounting [10], an emergency brake, and riding at a very low speed. The variables included in the study were rider speed and balance, position on the pavement, mental and physical workload. Note that the study did not include the so-called strategic level of the traffic task [11], and only considered actual cycling behavior. Thus, decisions on the purchase or use of an e-bike, or on aspects of route choice were not included in the study.

On ‘speed’ the study tested the following hypotheses. Because of the ‘pedal assistance’, we expected all bicyclists, regardless of age, to ride faster on an e-bike than on a conventional bike (H1).

On the effect of age we expected middle aged bicyclists to ride faster than older bicyclists on both bicycles (H2). For conventional bicycles such would be the case because of a lower physical strength and endurance in the older age group and their tendency to compensate for their limitations [12]. On the e-bike only ‘compensation for limitations’ would lead to a lower speed among the elderly.

As cyclists will adapt their speeds to the complexity of the road situations, we expected the differences in cycling speed between the two bicycle types to be greater in simple traffic situations, for instance on straight sections with a good view, than in complex traffic situation, for instance on left turns (H4).

In addition to speed, ‘mental workload’ is a relevant measure. This measure reflects the extent to which a task may exceed the road user’s capacities, which may result in errors and safety critical events. We do not know of previous studies that have measured workload for
cyclists, but it has frequently been used to assess the capacities of and task demands on car drivers [13, 14]. Several methods have been developed to assess workload, such as: addition of a secondary task, subjective assessments, and physiological measures such as heart rate variability. The present study applied the secondary task paradigm, which is based on the mechanism that the more workload is exerted by the primary task, the more performance on the secondary task will deteriorate [15]. Thus, a difference in secondary task performance on e-bikes and conventional bicycles serves as an indicator of differences in mental workload. A wide range of tasks can be applied as secondary tasks. Its choice mainly depends on the nature of the primary task. If visual demands are high in the primary task, as is the case in traffic, the Peripheral Detection Task (PDT) has shown to be a sensitive measure of mental workload [16-18]. This has been demonstrated in car simulator studies [e.g., 17] and also in driving in real traffic [16]. To our knowledge this is the first time that the PDT is used to study workload in a cycling task. The PDT is based on the finding that the functional visual field decreases, when mental workload increases (Miura, 1986), which results into elongated reaction times to stimuli and a higher number of misses.

PDT performance may be particularly relevant for elder road users. Studies suggest that, despite the fact that elderly car drivers compensate for their limitations [12], they still do not sufficiently adapt their behavior when traffic situation get more complex [19, 20]. This might explain why crashes with older drivers more often happen in complex maneuvers that require a division of attention, such as left turns [19, 21]. Assuming that this is also the case for elderly cyclists, we expected that mental workload of left hand turns will be higher for older bicyclists than for middle aged bicyclists (H3).

The results reported in this paper are limited to the main effects on speed and mental workload. It does not deal with the highly relevant interaction between speed and mental workload. Speed choice along with the choice of safety margins are the two behaviors that cyclists may use to control the mental workload. By choosing lower speeds and larger distances to danger zones, cyclists have more time to attend and respond to the safety relevant traffic features [22, 23]. However, speed choice of cyclists compared to car drivers creates an additional challenge and it directly affects the cyclist’s balance, especially at lower speeds [24, 25]. Thus not only speed and mental workload interact, also speed and balance do.

2. METHOD

2.1. Participants

About a thousand Invitation letters were sent to addresses in the direct surroundings of the location of the SWOV institute. People could participate when they were either between 30-45 years (the middle aged cyclists) of age or 65 years of age or older. Experience with riding on an e-bike was not required. Only participants were included that cycled regularly and were able to ride on both a conventional bicycle and an e-bike. In total sixty-one participants were recruited, in two age groups. From the sixty-one participants one participant was excluded, as his test was prematurely stopped for safety reasons. Two other participants were omitted, because the data was not properly saved and therefore unsuitable for analysis. Participation was rewarded with a € 25 gift card.

The characteristics of the remaining 58 participants were the following: Middle aged cyclists: n=29; 38% male; mean age = 37.7, SD = 4.3; Older cyclists: n = 29; 55% male; mean age = 69.9, SD = 4.2.
2.2. Materials and apparatus

In this study two bicycles were used, both equipped with sensors, cameras and data registration systems. They were identical except for the propulsion system. The e-bike was fitted with an electric engine in the rear wheel hub and a battery underneath the luggage. The electric engine only offered propulsion when the bicyclist pedalled, up to the maximum speed of 25 Km/h. The e-bike was the ‘Batavus Sorocco Easy’ (lady model 2012) and weighted 27.4 kg. The conventional bike was the ‘Batavus Sorocco’ (lady model 2012) and weighted 16.0 kg. Both bicycles were equipped with:

- An accurate speedometer to record actual cycling speed;
- A potentiometer at the steering shaft that could record steer angle and steer angle acceleration;
- A Global Positioning System (GPS) to record the location of the cyclists;
- A GoPro 3 Silver video camera at the end of a rod attached to the bicycle frame to capture the entire cyclist from the front;
- A 3D acceleration sensor, gyroscope and compass (ProMove 3D sensor) to register – among others – balance;
- A laptop to record the data and to run MATLAB for data sampling.

The laptop, the ProMove 3D sensor and the GPS were stored in a box on top of the luggage carrier.

Also the participants were equipped with devices:

- A PDT (fitted to the helmet) to measure mental workload and a control box to communicate by WiFi with the laptop;
- A heart rate monitor (wrist watch) to record physical workload;
- A helmet-mounted camera to record the participant’s head movements in combination with traffic situations.

2.3. Measures

Baseline measures
In order to control for individual differences in initial capacities, participant’s baseline heart rate, PDT performance, balance, and grip strength were recorded.

Cycling speed
Cycling speed was recorded and for each segment (section 1.5) the average speed and variance in speed.

PDT recorded mental workload
The PDT requires the participant to respond as quickly as possible to a red (LED) light, which is randomly presented in the peripheral field of view of the left eye, and mounted at the end of a rod fixed to the participant’s bicycle helmet. As recommended [26] this signal was presented about 20 cm from the participant’s eye and at a horizontal angle of 11-23 degrees, (see Figure 1). When the stimulus (the red light) was presented, participants had to react as fast as possible by pushing a button. This button was attached to their left thumb and could be pressed pushing their left thumb on the bicycle’s handlebars. Both the LED stimulus and push button were attached to a control box, stored in the participant’s small backpack. The random signal rate for the PDT was set at an interval of 3 to 5 seconds and the LED signal was visible for 1 second. Of each stimulus the response time (RT) was recorded (in milliseconds). Also it was recorded whether a stimulus had been missed, which as defined as no response within 2 sec-
onds after the onset of a stimulus. The control box in the backpack was connected to the laptop (by means of Wi-Fi) and the data was sampled directly through MATLAB.

![LED light for PDT and camera for forward view mounted on bicycle helmet](image)

**Figure 1.** LED light for PDT and camera for forward view mounted on bicycle helmet

**Head and body movements, and traffic situations**
A video camera (also a GoPro 3 Silver) was mounted on top of the bicycle helmet (see Figure 1). This video recorder captured the direction of the participant’s head movements. Video data of this camera and of the camera mounted at a rod which was attached to the bicycle frame, were sampled on a SD card situated in the camera and were later synchronized with the other data.

**Physical workload**
The heart rate of the participant was measured during the experiment as an intermediate for physical workload. The heart rate was collected with the MIO Alpha wrist watch and sampled at a frequency of 1 Hz. The data was stored (via Bluetooth) on an iPhone 4S and later synchronized with the data that was recorded on the laptop, utilizing the GPS time code. The data of the sensors, except the GPS data and the heart rate data which were sampled at 1 Hz, were sampled with MATLAB (7.14) at a frequency of 50 Hz.

Figure 2 offers schematic presentation of the instrumentation of the bicycle(s) and the participant.
2.4. Cycle route

All participants rode the same route. The course was approximately 3.5 kilometres long and was situated in Leidschendam, a city with approximately 28,000 inhabitants. The route included a residential area and a secluded bicycle path, both of which had been marked by orange direction signs to assist participants in finding their way. This route was chosen because of the variety of demands it placed on vehicle handling and information processing. Experimental sections on the route (i.e. straight sections, left turns, sharp left turns, and slope up, slope down) were selected in advance, since these represent common segments of road for any cyclist. To facilitate the prospective analyses, these segments were defined on the road by either natural or temporary self-made markings that indicated the start and end of each segment.
2.5. Procedure

Prior to the day participants were scheduled to do their test rides, they received a ‘demographic’ questionnaire (e.g. questions about their height, weight and the type of bicycle they use and purpose of their bicycle trips). The experiment was structured through the use of a protocol, in which every step of the test was defined. Participants were first informed about details of the study and prepped with the necessary equipment, before their initial grip strength, balance, heart rate and mental workload were measured (base line measurement). Secondly, participants rode a practice round on both the conventional bicycle and e-bike before each experimental ride, in order to get accustomed to the route, the bicycle and the secondary PDT task. The order in which participants rode on the e-bike and the conventional bike was counterbalanced across participants to mitigate possible learning effects. After the experimental ride participants were asked to perform four tasks on a fenced off parking lot, aimed to provide insight into actions regularly performed by cyclists (i.e. mounting and dismounting the bicycle, looking backwards, accelerating and keeping balance at low speeds). Thirdly, after the experimental rides on both bicycles were completed, the participants filled out a final questionnaire that was designed to give insights into their experience with both bicycles and to understand how participants reacted to sounds in the environment while cycling. Each experiment lasted approximately 2.5 hours and there were up to three participants planned each day. These participants were scheduled in 2013 from July through September and two participants were rescheduled in the middle of their experiment due to poor weather conditions.

Figure 3. Test course (yellow: outward bound; red: homeward bound)
2.6. **Experimental design and data synchronisation and statistical analysis**

Cycling behaviour of a group of older cyclists and a group of middle aged cyclists was compared when they cycled the same course in traffic alternately on a conventional bicycle and on an e-bike. Measured were longitudinal speed, heart rate (as a proxy for physical workload), mental workload (with the Peripheral Detection Task (PDT)) and ‘keeping balance’ (as proxy steering angle acceleration was measured). The course in traffic was divided in sections (straight sections, left turns, sharp left turns, and slope up, slope down). A $2 \times 2 \times 2$ mixed design was used. The within groups factor were bicycle type (conventional bicycle and e-bike) and road section (straight sections, turns to the left, sharp turns to left, slope up, slope down and the whole course) and the between groups factor was age (older bicyclist, middle aged bicyclist).

For the analysis all the collected data was imported into SQL and synchronized using an in-house made analysis tool. In the analysis tool, all previous identified segments were coded using the markings on the road and a similar specified marker on each bicycle that was captured with the camera facing the cyclist. This meant that the data would be analysed over the whole course (approximately 3.5 km long), two straight sections (about 180 meters each), two slopes up, two slopes down, two sharp left turns (variable in length) and three left turns marked around 21.6 meters before and 13.5 after the turn.

For comparison within groups, paired t-tests were applied and for the comparison between groups, independent t-tests were applied. Repeated Measures ANOVA was applied in order to test if there were any interaction effects. An alpha level of .05 was used to determine statistical significance and all tests were two-tailed. All data sets were first analysed if the assumptions for parametric testing were met. If these assumptions were not met, instead of the paired t-test, the Wilcoxon signed-rank test was applied and instead of the independent t-test the Mann-Whitney U test was applied.

3. **PRELIMINARY RESULTS**

This section only presents the results concerning speed and mental workload and only for performance on: a) the whole length of the route b) straight sections, c) left turns.

3.1. **Speed**

Figure 4 presents the average speed at all points on the route of the two age groups and the two bicycle types, and shows that at all segments cyclists on e-bike rode faster than on conventional bicycles. That held true for both age groups. Middle aged cyclist on an e-bike had the highest average speed and older bicyclist on a conventional bike had the lowest average speed. For most parts of the track, middle aged bicyclists on a conventional bike rode about as fast as older bicyclists on an e-bike. The peaks in Figure 4 represent sections in the test course where participants went down a slope. The lows represent sections in the test course where participants had to make a turn (either to the left or to the right) or went up a slope. At the lowest point in Figure 4 (at around 1760 meters from the starting point) participants arrived at the turning point of the course. Here they had to make a sharp turn and almost came to a full stop in order to start with the homeward bound part of their trip. At the peaks (slope down) and the lows, where cyclists had to turn, the mean speeds of the two age groups and the two bicycle types converge. In contrast, at straight sections these speeds diverge, both for age group and for bicycle types.
Figure 5 shows the mean speeds of the two age groups and two bicycle types at the straight sections in the course and in left turns at intersections in the course. Independent t-tests revealed that on both bicycle types older cyclists had a significantly lower mean speed than middle aged bicyclists, both at straight sections (conventional $t(56) = 4.60, p < .001$; e-bikes $t(56) = 4.38, p < .001$) and on left turns (conventional $t(56) = 5.54, p < .001$; e-bikes $t(56) = 5.19, p < .001$). Further, Paired t-tests revealed that both middle-aged and older bicyclists rode significantly faster on an e-bike than on a conventional bike, both at straight sections (middle aged cyclists $t(28) = 12.38, p < .001$; older cyclists $t(28) = 13.39, p < .001$) and in left turns (middle-aged cyclists $t(28) = 5.52, p < .001$; older cyclists $t(28) = 7.90, p < .001$). These results confirm the hypothesis that all cyclists, regardless of age, ride faster on an e-bike than on a conventional bike (H1) and the hypothesis that middle aged bicyclists ride faster than older bicyclists both on a conventional bike and on an e-bike (H2). Repeated Measures ANOVA revealed that there were no interaction effects. The line for the middle aged bicyclists and the line for the older bicyclist in Figure 5 run almost parallel, thus it is quite obvious there are no interaction effects. Older cyclists ride slower than middle aged cyclist and do this in about the same amount on conventional bikes and on e-bikes at both straight sections and in left turns at intersections.
The effect of ‘complexity’ was significant for both age groups. In simple traffic situations, that is on straight sections, middle aged bicyclists rode on average 3.7 km/h (SD = 1.6) faster on an e-bike than on a conventional bike. For older bicyclists this difference was 3.7 km/h (SD = 1.5). For complex traffic situations, that is on left turns at intersections, for middle aged cyclists this difference was only 1.5 km/h and for older bicyclists 1.7 km/h. For both groups the interaction between bicycle type and complexity were significant; $F(1,56) = 150.91, p <.001$. As hypothesized cyclists (both middle aged bicyclists and older cyclist) on an e-bike strongly reduced their speed in complex situations, and mainly took advantage of the electric pedal support in the simple situations (H4).

3.2. Mental workload

Mental workload was assessed before the rides (baseline), over the total ride, and over segments of the rides. These segments were the combined complex sections (left turns at intersections) and the combined simple sections (straight sections). First the main effects are presented followed by the interaction effects.

**Base line versus total ride**

Baseline RTs were significantly faster ($M = 208.5$ ms, $SD = 71.9$) than RTs during the total ride ($M = 544.8$ ms, $SD = 128.3$; $t(46) = 11.8, p <.001$), with no significant difference for bicycle type. Hit rate was not normally distributed. The Wilcoxon signed-rank test revealed that the hit rate (98.9%) was significantly higher at baseline than during the ride (83.2%), $Z = 5.706, p <.001$, again with no significant difference for bicycle type. Baseline performance did not differ between the age groups, not for RTs ($t(45) = 0.991, p = .327$), nor for hit rate ($Z = 1.238, p = .218$). These results suggest that irrespective of age group or cycle type, in cycle ride mental workload is higher than on a PDT task without cycling as the primary task.
**Main effect of Bicycle type over the total ride**

A paired t-test revealed there was no difference in RT between an e-bike ride and a ride on a conventional bike, $t(46) = .461, p = .65$, and also the Wilcoxon signed-rank test on hit rate did not show a significant difference, $Z = .449, p = .646$. This suggests that both age groups managed to keep mental workload stable, irrespective of bicycle type.

**Main effect of complexity: straight sections versus left turns**

A paired t-test revealed that participants had a significantly longer RT when they turned left ($M = 604.7 \text{ ms}, SD = 145.7$) than when they cycled on straight sections ($M = 506.9 \text{ ms}, SD = 139.6$), $t(46) = 5.55, p < .001$. Also, the Wilcoxon signed-rank test revealed that the percentage hits was significantly lower at left turns (75.2%) than on straight sections (89.3%) $Z = 5.48, p < .001$. These results indicate that regardless of bicycle type and age group, a left turn is mentally more strenuous than cycling on straight sections.

**Main effect of age**

An independent t-test revealed that regardless of bicycle type, the RT of middle aged cyclists ($M = 489.7 \text{ ms}, SD = 98.9$) was significantly shorter than that of older cyclists ($M = 597.6 \text{ ms}, SD = 132.9$), $t(45) = 3.15, p < .01$. However on the hit rate, the Mann-Whitney U test did not result in differences between the age groups, $U = 324.5, p = .30$. As no significant difference in mean RT was found in the base line condition, the results indicate that regardless of bicycle type, cycling is mentally somewhat more strenuous for older cyclists than for middle aged cyclists.

**Interaction effects**

Of all possible two way and three way interactions (Bicycle type × Age group × Complexity) Repeated measures ANOVA showed that only the two way interaction Age × Complexity was significant; $f(1,45) = 5.517, p = .02$. Compared to middle aged cyclists, older cyclists had significantly longer RTs at left turns than at straights sections (See Figure 6).

![Figure 6. Response times of middle aged cyclists and older cyclists at straight sections and while turning left at intersections. Error bars present +/- 1 standard error (SE).](image_url)
4. DISCUSSION

The study aimed to investigate differences in speed choice and mental workload for middle-aged and elderly cyclists on e-bikes and conventional bicycles. The results show that all cyclists, regardless of age, ride faster on an e-bike than on a conventional bike. Cyclists adapt their speed choice to the complexity of the traffic situations. When these are relatively simple, i.e. straight sections, this speed difference is almost 4 km/h. In contrast, in complex situations, i.e. at left turns, this difference drops to 1.5 km/h. Further, speed choice appears not only to be related to complexity but also to the limitations in physical strength and vehicle handling skills. That physical strength also plays a role became apparent on the downward slopes. There, even conventional bicycles reached speeds of about 25 km/h, which only slightly differed from speeds on e-bikes in these situations. Further, that vehicle handling influences speed choice became apparent at the sharp corner. Here speed dropped to extremely low values, both for conventional bicycles and e-bikes.

In contrast to speed, mental workload remained rather stable. For both age groups, mental workload on an e-bike did not differ from the workload on a conventional bicycle. For older age groups the cycle task exerted a higher mental workload than for middle-aged a group, but it was the same for both bicycle types. Although for elderly cyclists mental workload was also higher in the simple traffic situations, the workload increased even further in the complex traffic situations. That was the case for both bicycle types.

These preliminary results indicate that cyclists manage to keep their mental workload quite stable and modify the task demands by adapting their speed choice. The speed patterns further suggest that aside of mental workload, physical strength and vehicle handling affect speed choice. The influence of these factors are quite similar for both bicycle types and both age groups. Although speed differences between e-bikes and conventional bicycles appear to be small, it still can have a great influence on safety. Not just because of the large impact on crash risk, but also because of the effect of higher speeds on stability and vehicle handling in different manoeuvres. Moreover, older cyclist seem to experience a higher workload at left turns and at the same time adapt their cycling behaviour insufficiently. This might be a reason for concern.

Previous research [26] showed that older bicyclist often crash when they make a left bend turn on intersections. It is possible that the combination of a higher mental workload and a higher speed in complex situations may contribute to a higher crash rate.

As discussed in the introduction, the safety implications of these findings need further exploration. Far more data have been collected on the cycle routes that have not been reported here, such as the stability of the bicycles, the interactions with other road users, and the information about the cyclist’s history, health, cycling experience. Further, the present study was expanded to explore the handling characteristics of the bicycle types for the different age groups. To that end, the participants had to carry out different subtasks, such as an emergency brake, looking over ones shoulder, riding at a very low speed, and mounting and dismounting a bicycle. These data have not been analysed yet. Thus, all results reported here are preliminary and may be modified when the results from these other variables and extra tasks are also taken into account.

REFERENCES


