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The efficacy of a brief hazard perception interventional program for child bicyclists to improve perceptive standards

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ABSTRACT

Introduction: Even though child bicyclists are highly vulnerable in traffic only few studies focused on providing child bicyclists with means to enhance their abilities to deal with the complexity of dynamic traffic situations. The current study therefore evaluated whether a brief hazard perception intervention might be effective to improve hazard perception skills in child bicyclists towards a level more comparable to adult bicyclists.
Methods: Eighty children of the fourth grade (9.03 ± 0.43 years; 34 girls) and forty-six adults (34.67 ± 14.25 years age; 24 woman) first performed a Hazard Perception test for bicyclists. Response rate, reaction times, first fixation, duration of the first fixation, dwell time and total number of fixations on the events were measured. Next, the children took part in the HP intervention in which video clips of dangerous traffic situations were presented. The intervention comprised two classroom sessions of one hour (1/week). A post-test was performed one day after and the retention-test three weeks after the intervention.
Results: Children responded to more covert hazards immediately after the intervention ($p < 0.05$), but did not improve their response rate for overt hazards. Reaction times for the covert hazards improved on the post-test ($p < 0.001$) compared to the pre-test but this effect was reduced on the retention test. There was no effect of the intervention for entry time of the first fixation but the duration of the first fixation increased for the covert hazards ($p < 0.05$). Children made fewer fixations on the event compared to adults ($p < 0.001$), except for the covert hazards on the retention-test. The training also increased the number of fixations for the overt hazards on the post-test ($p < 0.001$) and the retention-test ($p < 0.001$) but only increased on the retention test for the covert hazards ($p < 0.001$).
Conclusion: The results demonstrated that a brief intervention for training hazard perception skills in child bicyclists is able to improve children's situation awareness and hazard perception for potential dangerous situations. The training, however, was too short to improve children to higher adult levels.

1. Introduction

As the number of bicyclists in Europe is increasing (DEKRA Automobil GmbH, 2011), resulting in both positive health-related and environmental benefits (de Hartog et al. 2010; Oja et al., 2011), there is also a downside attached to this fortunate trend. Growing levels of bicycle use have led to an increase in the number of bicycle accidents in which mainly children (under the age of 14) and older cyclists (above the age of 65) are involved (Carpentier and Nuyttens, 2013; Maring and van Schagen, 1990). Bicycle accidents in Europe represent 7.8% of all road fatalities indeed (European Commission, 2015). Moreover, in Flanders (Belgium) 9- to 14-year-old children represent 10% and 14- to 19-year-old-children up to 11% of all bicycle casualties (Carpentier and Nuyttens, 2013). Despite this unenviable trend only few studies focused on providing child bicyclists with means to enhance their abilities to deal with the complexity of dynamic traffic situations (Hill et al., 2000). In the context of lifelong traffic education, the current study therefore aims to improve the ability of young bicyclists to negotiate complex traffic situations through a brief hazard perception training.

1.1. Review of the literature

Bicycling in traffic occurs at higher speeds compared to walking or lower speeds compared to driving, requiring a more complex interaction between perceptual and motor skills such as simultaneously coordinating control over the bicycle in relation to other faster moving objects in the environment (cars) e.g. checking the shoulder for traffic from behind. Bicycling safely through traffic therefore largely depends on the child's ability to simultaneously combine motor bicycling skills (e.g. steering, pedalling or signalling), as well as perceptual-motor skills

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(e.g. hazard perception and anticipation) which have been demonstrated to improve through deliberate practice (Briem et al., 2004; Ducheyne et al., 2013a,b; Ellis, 2014; Zeuwts et al., 2017a,b). Given that young children are physically and mentally not mature yet, they are limited in their capabilities to sufficiently cope with dynamic traffic situations. Children place motor over cognitive task when they have to perform both at the same time (Schaefer et al., 2008). Accordingly, children have difficulties detecting the presence of traffic, distinguishing safe from dangerous locations, making time-to-contact judgments, coordinating and processing visual information, and integrating the relevant information into a holistic appreciation of the situation (Ellis, 2014; Foot et al., 1999; Meyer et al., 2014; Plumert et al., 2011; Thomson et al., 2005). In support of these findings young children have been suggested to primarily focus on the most salient factor in the environment (Meir et al., 2015a; Zeuwts et al., 2017a). For example a car in front of the bicyclist is attended while the intersecting street from the right goes unnoticed. It can therefore be suggested that young bicyclists display poorer situation awareness compared to adults which hampers them to attend to the relevant visual information (perception; SA1), decide whether or not a situation might contain risk (comprehension; SA2) and to make predictions regarding the future development of the situation (projection; SA3) (Endsley, 1995; Meir et al., 2015a, 2013; Rosenbloom et al., 2015). Situation awareness is considered to be closely related to hazard perception (Wetton et al., 2011). Hazard perception refers to the ability to "read" the road and anticipate upon the forthcoming situation. Since novice drivers have been shown to overlook more traffic conflicts and displayed more difficulties with detecting the elements that might have predicted the dangerous situations (Borowsky et al., 2010; Huestegge et al., 2010; Wetton et al., 2011) it can be suggested that hazard perception skills are not utterly dependent on maturation but on experience too. A number of studies therefore aimed to improve young learner drivers' and children pedestrians' hazard perception skills.

PC-based hazard perception training interventions in young drivers have been reported to effectively improve learner drivers' ability to detect hazardous situations up to the level of more experienced drivers (Isler et al., 2009; Pradhan et al., 2009, 2005; Taylor et al., 2014). In an attempt to accelerate the development of perceptual-motor skills in children, computer-based learning strategies have been effectively adopted to drive educational interventions (Meir et al., 2015b; Schwebel et al., 2016; Thomson et al., 2005). In the simulation intervention of Thomson et al (2005), children had to help an avatar to cross several intersections when 'walking to the park'. Each time a child chose an unsafe gap, the image froze and screeching brakes were heard, followed by the avatars' ghost departing from its body. This was used to open discussion and provide the participant with feedback. In addition, Meir et al. (2015b) presented children with 11 traffic scenarios from the perspective of a child pedestrian. Children were required to press the response button every time they detected a dangerous situation. Then, the scenarios were replayed from a higher point of view to improve children's perception regarding the situations. In the second part of the intervention, children were presented with three pairs of traffic scenes. Each pair represented the same environment but from a different perspective to improve their situation awareness. More recently, Schwebel et al. (2016) aimed to improve children's road crossing skills when presented with a virtual reality training. Children stood on a simulated curb in front of the monitors on which the virtual road was presented. Whenever they felt safe to cross the street, they stepped of the curb onto a pressure plate. First person view then changed to third person view which allowed children to view their own crossing. A cartoon appeared after each crossing to provide children with feedback. In general, trained child pedestrians (7–11 years old) significantly improved their road crossing behaviour (e.g. quicker road crossing, better aligned road crossing, and fewer missed opportunities), conceptual understanding and awareness to potential hazardous situations compared to the controls. With respect to cycling, Zeuwts et al. (2017a) reported that child bicyclists' performance on a tailored hazard perception test was poorer compared to the performance of experienced adult bicyclists, but a brief hazard perception training for child bicyclists resulted in lower response latencies, higher response rates and better cognitive processing of the potential dangerous situations compared to a control group (Zeuwts et al., 2017b).

1.2. Objectives

Even though the beneficial effects of hazard perception interventions in learner drivers and child pedestrians have been extensively described in the literature, there is only limited evidence available with respect to bicycling. It is therefore unknown whether there is a carry-over effect to cycling, especially given that bicycling requires a more complex coordination between perception and action and experience is often task specific (e.g. cycling between traffic at lower and higher speeds while controlling a bicycle and looking for hazards) (Briem et al., 2004; Plumert et al., 2011; Zeuwts, 2016). Furthermore, to measure the effectiveness of the intervention, studies often compare learner drivers or child pedestrians to more expert drivers or adult pedestrians, who are considered the standard for comparison. Also adult bicyclists can be considered more expert bicyclists as they, should have mastered their bicycle handling skills and traffic skills through repetitive practice, the current study aims to address whether a brief hazard perception intervention is effective to improve hazard perception skills in child bicyclists towards the level of more experienced adult bicyclists. Given that access to the visual information is essential for evaluating the first level of situation awareness and precedes anticipation, visual behaviour of the participants will be documented by means of eye tracking methodology.

2. Methods

2.1. Participants

2.1.1. Child bicyclists

In total, 30 elementary schools received an invitation to participate in this study. However, only four schools were willing to cooperate in the hazard perception test and the intervention. Given that higher cognitive training should take place when basic bicycling skills have been obtained (Deery, 1999; Meir et al. 2014), 80 fourth graders (9.03 ± 0.43 years of age; 34 girls) with at least two years of bicycling experience were included since Ducheyne et al. (2013a,b) and Briem et al. (2004) reported that children should be able to control their bicycle around the age of nine and start to bicycle more independently. Children were given an informed consent which their parents read and signed for approval.

2.1.2. Adult bicyclists

In addition, 46 adults (34.67 ± 14.25 years of age; 24 women) performed the hazard perception test to compare hazard anticipation skills between children and adults. Adults were recruited from the department of Movement and Sport Sciences. Adults were allowed to participate if they used their bicycle on a regular basis (four times a week), and used their bicycle to bicycle to school when being a kid. Adults read and signed the informed consent prior to the testing. The study protocol was approved by the Ghent University ethical committee.

2.2. Apparatus and protocol

2.2.1. The hazard perception test

The Hazard Perception test (Hptest) consisted of fourteen video clips (± 30 s) which were videoed with a GoPro Hero2 camera (30 Hz, full HD and 170° field of view) mounted on the handlebar of a bicycle. Each film clip from the perspective of the bicyclist included a variety of

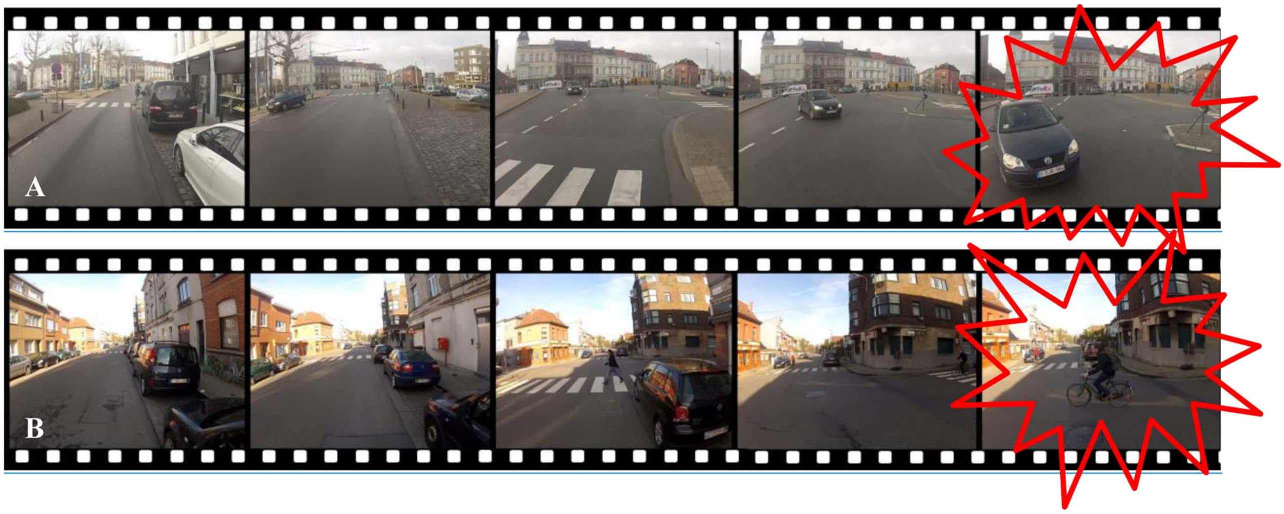

Fig. 1. (A) represents the development of an overt hazard. A driver in the opposite direction of the bicyclists intends to turn left but initially oversees the cyclist. (B) represents the development of a covert hazard. A traffic sign indicates that the intersecting street from the right has priority. Proper view on the street from the right is blocked by the houses hiding the oncoming bicyclist until the last moment.

Table 1
Description of the hazardous situations, their corresponding timeframe and correct answer.

Clip	Timeframe	Hazard	Type	Description of the video
1	4.97 s	Car	Overt	A car in the opposite direction of the cyclists is about to turn left but oversees the cyclist.
2	2.83 s	Pedestrian	Overt	A woman coming out of a double parked car, steps onto the bicycle path from behind another car.
3	14.30 s	Van	Overt	A van passes the bicyclist. The driver indicates he's about to park in front of the bicyclist.
4	5.26 s	Bicyclist	Overt	A bicyclist is not paying attention and enters the bicycle path just in front of the bicyclist
5	2.29 s	Pedestrian	Covert	A men enters the street from behind a van.
6	4.87 s	Pedestrian	Covert	A man opens the door of his parked car and steps out of the car.
7	5.66 s	Car	Covert	View on the car coming from a street on the right side is blocked by bushes.
8	2.92 s	Pedestrian	Covert	View on the pedestrian at a pedestrian crossing is blocked by a container.
9	5.87 s	Bicyclist	Covert	View on a cyclists coming from the street on the right is blocked by houses.
10	10.43 s	Pedestrians	Covert	A group of people is unloading a bus, crossing the street from behind the bus. When the bicyclist passes, a man suddenly steps from behind the bus onto the street.
11	15.58 s	Bicyclist	Covert	A sign and road markings indicate a bicyclist crossing. View on the crossing is limited due to parked cars and vegetation. Distracted bicyclists appear, however do not cross the road.
12	12.51 s	Car	Covert	View on the street from the right is limited. A car from the right enters traffic in front of the bicyclist.
13	5.02 s	Van	Covert	A van is parked on the street in front of a pedestrian crossing. A pedestrian comes from behind the van but waits for the bicyclist to pass.
14	3.43 s	Van	Covert	View on a van coming from the right is blocked for the bicyclist due to vegetation

typical Belgian traffic situations and road designs. The film clips contained at least one hazardous situation, which were classified into overt or covert hazards (Vlakveld 2011). Overt hazards represent situations in which other visible road users might start to act dangerously over time (see Fig. 1A). Covert hazards on the other hand, refer to potential hazardous situations in which other road users are hidden from view through buildings, parked cars, vans or vegetation (see Fig. 1B). Participants were not informed regarding the number of hazards in each clip. The detailed scenario for each of the 14 clips can be found in Table 1.

Film clips were presented on a computer screen (22 in.) with a visual angle of 40° horizontally × 30° vertically. A Remote Eye tracking Device (RED) of SensoMotoric Instruments (SMI, Teltow, Germany) was mounted underneath the computer screen to track participant's gaze behaviour during the test. SMI Experiment Center 3.4 software was used to run the experiment and display the video clips on the computer screen. The iView X recording software of SMI enabled us to simultaneously track eye movements (binocular) and reaction times of the participant at 120 Hz.

Children were tested during regular school time. When children entered the testing room at their school; they were asked to take a seat ± 70 cm in front of the computer screen (see Fig. 2). Children received a brief standardized explanation regarding the experiment and were told to imagine they were actually cycling the bicycle themselves.

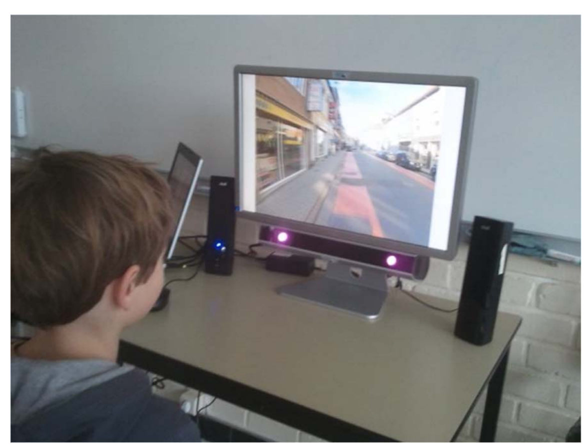

Fig. 2. A child performing the hazard perception test.

Each time they detected a hazardous situation in the video clip which required them to brake or steer in order to avoid a potential collision, they had to press the mouse button (once) as soon as possible. Following the explanation, the eye tracking device was calibrated using a five point grid. Only calibration deviations lower than 1° were accepted. When the calibration was completed, the children were presented with the 14 film clips. To prevent from cheating, participants were asked to indicate each hazard for which they had responded when the video clip was ended. Calibration accuracy of the eye tracking device was checked in the middle and at the end of the experiment. The PC-based hazard perception test was performed pre-training, post-training and after three weeks on the retention-test. The video clips in the post-test and retention-test were the same as in the pre-test but were presented in randomized order. Additionally, adults performed the same hazard perception test as the children at the faculty of Movement and Sport Sciences, after they had read and signed the informed consent.

2.2.2. The hazard perception training

After the pre-hazard perception test was completed, children received the hazard perception training. In this training intervention, video clips of overt and covert potential dangerous traffic situations, different from the hazard perception test were projected on a projection screen (1,5 m × 2 m) in front of the classroom. Film clips for the intervention were evaluated by three experts (driving instructors with at least 15 years of experience) and were ranked from simple standard traffic situations to more dynamic and complex traffic situations with multiple dangers. Since Meir et al. (2014) demonstrated that child pedestrians primarily tended to rely on salient visual information and children are considerably smaller compared to adults, the current intervention included video clips from the perspective of both adult and child bicyclist's hazards to improve understanding regarding hidden (covert) hazards. Furthermore, a variety of landscapes, road designs and hidden (covert) hazards that actually materialized were included.

The training was performed in the children's classroom and consisted of two lessons of approximately 50 min each. The first lesson of the hazard perception training was performed two days after the hazard perception test. First, children received verbal instructions regarding the intervention after which they were provided with the opportunity to ask questions. Then, the first lesson started with film clips of different hazardous situations progressing from simple traffic situations to more complex and dynamic hazardous traffic situations. Children were asked to imagine they were bicycling in the video clip themselves and were required to raise their hand as soon as they thought they would have to brake or stop to avoid a potential collision. Every time a child raised his or her hand to indicate he or she would have stopped or braked, the film clip was paused and the event was discussed in group. The teacher asked the children “what might have happened next?” or “what might have predicted a possible collision?” After the discussion, the film clip was continued until the next event or until the end of the clip. At last, the clip was replayed and children were provided with the necessary information regarding where to look, what to look for, what cues might have predicted the dangerous situation or what might have happened. Furthermore, children were told what correct behaviour or actions could be undertaken. These instructions were composed together with three experts regarding driving education. One week after the first training session, children received the second lesson which was followed by the post-test one or two days later. A retention-test was performed three weeks after the post-test.

2.3. Data analysis

First the critical hazard perception interval for each hazard in each clip was determined. This interval refers to the time window in which the hazard appeared for the first time (ms) until the time stamp (ms) when the hazard became inevitable. This critical hazard perception interval was unanimously validated by three experts. Furthermore, thanks to the Area Of Interest-editor (AOI) of the gaze analysis software package BeGaze 3.4 (SensoMotoric Instruments, Teltow, Germany), dynamic AOIs could be determined and concur with the critical hazard perception interval. AOIs can be used to include important visual areas in the video clip which the bicyclist must have seen to anticipate potential collisions. In the current paper, AOIs consequently refer to the hazards. Using the ‘SMI Event Detection’ algorithm in BeGaze 3.4. gaze behaviour of the participants towards the AOIs could be determined.

2.3.1. Tracking ratio

Before further analysis was conducted, tracking ratio or the percentage of time in which gaze was accurately registered during the trial was computed for all the participants. Given that in eye tracking experiments there is often a considerable loss of data due to excessive head movements or eye blinking, participants with a tracking ratio below 80% were excluded for further analysis. Two children were excluded for further analysis due to low tracking ratio.

2.3.2. Measures

Six measures were taken into account for the analysis of each film clip:

- *Response rate* refers to the number of participants responding correctly to the hazard (one point awarded for this video clip) or not (zero points awarded in this clip). When a participant responded to all of the hazards correctly, and indicated them afterwards in the questionnaire, he or she received a maximum score of 1.
- *Reaction times* for each hazard were measured relative to the critical hazard perception interval. Only when the participant indicated the correct hazardous situation in the short questionnaire following each clip as indicated in Table 1 reaction times were included for further analysis.
- For gaze behaviour the *entry time of the first fixation* on the hazard or the timestamp in which the participant fixated the AOI for the first time (s) was calculated. A fixation was taken into account when the eye remained still for at least 120 ms within an area of 1° in line with Duchowski (2007) and Holmqvist et al. (2011).
- The *first fixation duration* was defined as the duration of the first fixation on the hazard.
- *Dwell time* refers to the sum of all fixation durations and saccades that hit the respective hazard.
- The *number of fixations* corresponds to the amount of fixations the bicyclist made on the hazard (AOI).

2.3.3. Statistics

First, the effect of the training intervention in the child bicyclists on the dependent variables was conducted using a Linear Mixed Model (LMM) analysis with repeated measures and random intercept. Multilevel analysis was chosen over a repeated measures ANOVA as participants who did not react for or failed to look at a hazard were not automatically excluded from the analysis. The first model included one random effect; time (pre-post-retention). For the repeated measures, the repeated covariance type ‘diagonal’ was chosen while for the random effect the ‘ARH1’ covariance type was selected since both types resulted in the model with the best fit (lowest AIC). Estimation was set as Restricted Maximum Likelihood (REML) and estimated marginal means for each interaction effect were obtained. Furthermore, a second LMM was used to compare the results of the children in the pre-test, post-test and retention-test with the test results of the adults using one fixed effect for group (children vs. adults). Significance levels were set at $p \leq 0.05$.

3. Results

3.1. Response rate and reaction time

With respect to *response rate* presented in Fig. 3A, children responded to fewer overt hazards (0.80) in the pre-test compared to the adults (0.87). However, although the training did not result in significantly higher response rates for the overt hazards in children, the difference in response rate between children and adults disappeared for

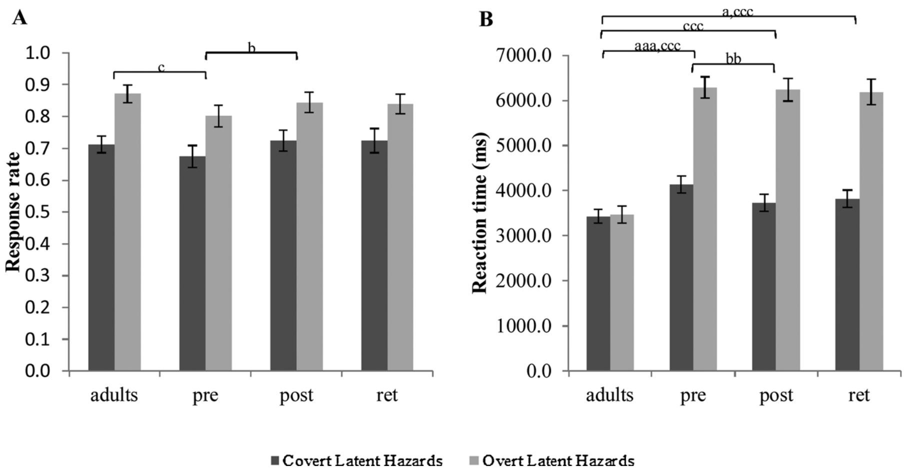

Fig. 3. Mean response rate (A) and reaction times (B) for the adults and children on the pre-test, post-test and retention-test for overt and covert latent hazards.
aaa = $p > 0.001$, aa = $p < 0.01$, a = $p < 0.05$, (a) = $p < 0.1$ or trend for the difference between adults and children for the covert hazards.
bbb = $p > 0.001$, bb = $p < 0.01$, b = $p < 0.05$, (b) = $p < 0.1$ or trend for the difference between pre-test and post-test or pre-test and retention-test in children for the covert hazards.
ccc = $p > 0.001$, cc = $p < 0.01$, c = $p < 0.05$, (c) = $p < 0.1$ or trend for the difference between adults and children for the overt hazards.
ddd = $p > 0.001$, dd = $p < 0.01$, d = $p < 0.05$, (d) = $p < 0.1$ or trend for the difference between pre-test and post-test or pre-test and retention-test in children for the overt hazards.

the post-test (0.84) and the retention-test (0.84). Regarding the covert hazards, there was no significant difference between children's response rate in the pre-test (0.67), post-test (0.73) and retention-test (0.72) compared to the response rate of the adults (0.71). Nevertheless, trained children responded more to covert hazards in the post-test compared to the pre-test (detailed statistics are provided in Appendices 1–4 in Supplementary material).

As for the *reaction times* presented in Fig. 3B, children displayed significant longer response latencies to the overt hazards in the pre-test, post-test and retention-test compared to the adults. The training did not result in significant improvements for the response latencies to the overt hazards. For the reaction times to the covert hazards on the other hand, children showed higher response latencies compared to the adult bicyclists in the pre-test and the retention-test, but not in the post-test. Indeed, children significantly improved their reaction times for the covert hazards on the post-test compared to the pre-test. There was no difference with respect to gender for any of the variables ($p > 0.05$; see Appendix 9 in Supplementary material).

3.2. Gaze behaviour

For gaze behaviour on the hazardous events, four measures have been analysed. Regarding the *entry time of the first fixation* on the hazardous situation, child bicyclists fixated significantly earlier on the overt hazards in the retention-test compared to the adult bicyclists (Fig. 4A). Furthermore, child bicyclists fixated later on the covert latent hazards in the pre-test compared to the adult bicyclists. However, child bicyclists only tended to fixate later on the covert hazards in the post-test and in the retention-test with respect to the adult bicyclists. There was no significant effect of the training on the entry time of the first fixation on the overt or covert latent hazards. As for the *duration of the first fixation* on the hazards, no differences were found for the overt hazard between adult bicyclists and child bicyclists, however, child bicyclists showed significant longer first fixation durations on the covert hazards in the pre-test, post-test and retention-test compared to the adults (Fig. 4B). On the other hand, the training did not result in any significant change in the duration of the first fixation. For *dwell time* on the hazards, presented in Fig. 4C, child bicyclists demonstrated significant shorter dwell times on the overt hazards in the pre-test, post-test and the retention-test compared to the adult bicyclists. Furthermore, child bicyclists demonstrated shorter dwell times on the covert hazards too in the pre-test and the post-test compared to the adult bicyclists. On the retention-test however, child bicyclists tended to fixate longer on the covert later hazard compared to the adult bicyclists. The training resulted in significant longer dwell times for the overt hazards on the post-test compared to the pre-test and for the covert hazards on the retention-test compared to the pre-test. Regarding the *number of fixations* on the hazard, child bicyclists fixated fewer on the overt hazards compared to the adult bicyclists in the pre-test, post-test and the retention-test (Fig. 4D). A similar result was found for the covert hazards, where the child bicyclists fixated the covert hazards fewer compared to the adult bicyclists in the pre-test and the post-test. In addition, the training resulted in a significant increase in the number of fixations on the overt hazards in the post-test and the retention-test compared to the pre-test. As for the covert hazards, the training only increased the number of fixations on the hazard in the retention-test compared to the pre-test. There was no difference for any of the variables with respect to gender ($p > 0.05$; see Appendix 9 in Supplementary material) except for dwell time indicating that boys looked slightly longer at the covert hazards compared to girls, but this effect was not apparent when time was added as a variable. We refer the reader to appendices one, two and five to eight for more detailed statistics regarding gaze behaviour which are provided as Supplementary material.

4. Discussion

Only few studies have attempted to evaluate the effectiveness of a brief hazard perception training to improve child bicyclists' ability to perceive and anticipate upon potential hazards towards adult-like levels. This study therefore examined hazard perception in child bicyclists before (pre-test), after (post-test) and three weeks after (retention-test) the intervention and compared the results of the child bicyclists to experienced adult bicyclists. The results suggest that the training improved child bicyclists' response rate and response latencies for the covert hazards surpassing adult levels. Gaze behaviour of child bicyclists on the post-test and the retention-test on the other hand demonstrates that children's visual scanning behaviour – knowing where to look for potential hazards – did not completely improve towards the level of adult bicyclists suggesting that training of specific visual skills requires more extensive exercise.

The finding that child bicyclists systematically demonstrated longer response latencies and entry times of the first fixation on the hazard compared to more experienced adult bicyclists is in agreement with the findings of Zeuwts (2016). Zeuwts recently suggested that child bicyclists operate from a more idiosyncratic perspective, rather than from a more integrated holistic perspective. Child bicyclists will primarily rely on salient visual stimuli, for example a conspicuous car in front of the bicyclist making a turn which is referred to as overt hazard, or asses the danger of traffic hazards based a single visible characteristic (Meir et al., 2013). This reliance on salient visual stimuli may in turn explain the lack of difference in visual behaviour between children and adults with respect to overt hazards. In concordance with the concept of situation awareness of Endsley (1995) that has often been cited to explain

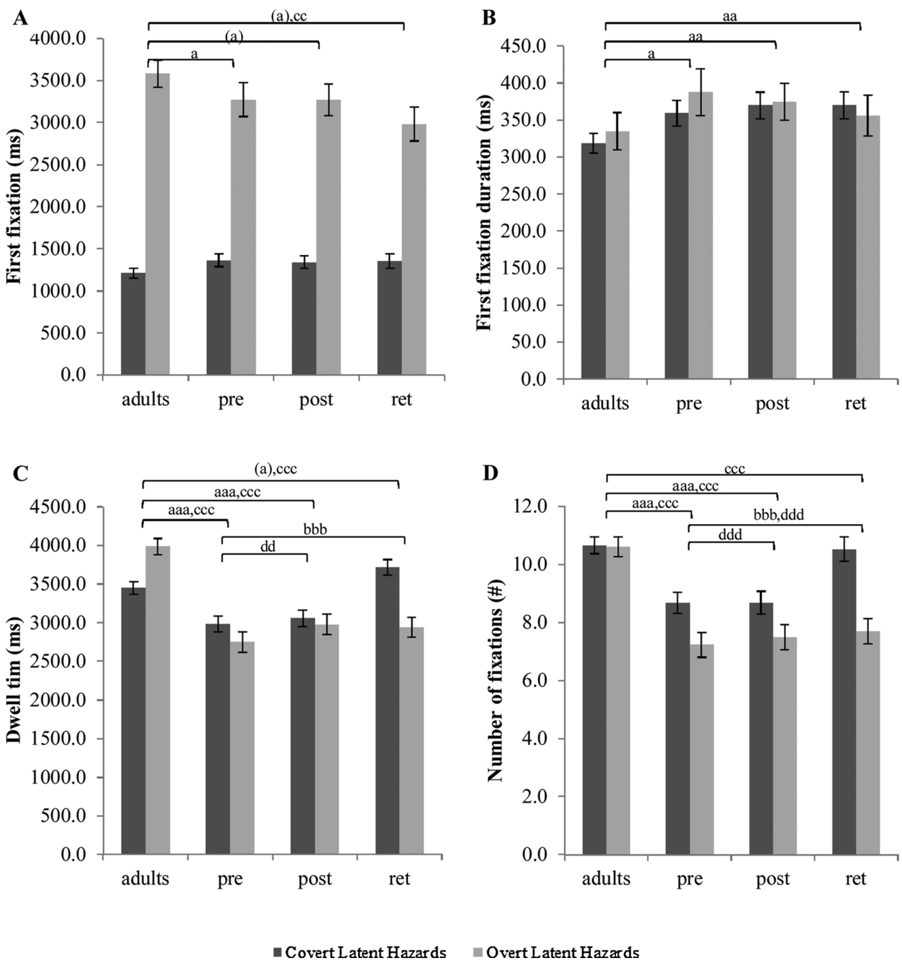

Fig. 4. Mean entry time of the first fixation (ms) on the overt and covert hazards (A), the duration of the first fixation (B), dwell time (ms) on the hazards (C), and the number of fixations on the hazard (D) for adult bicyclists and child bicyclists in the pre-test, post-test and the retention-test.
aaa = $p > 0.001$, aa = $p < 0.01$, a = $p < 0.05$, (a) = $p < 0.1$ or trend for the difference between adults and children for the covert hazards.
bbb = $p > 0.001$, bb = $p < 0.01$, b = $p < 0.05$, (b) = $p < 0.1$ or trend for the difference between pre-test and post-test or pre-test and retention-test in children for the covert hazards.
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ddd = $p > 0.001$, dd = $p < 0.01$, d = $p < 0.05$, (d) = $p < 0.1$ or trend for the difference between pre-test and post-test or pre-test and retention-test in children for the overt hazards.

differences in hazard perception between young novice drivers and more experience drivers (Gugerty, 2011, 1997; Underwood et al., 2012), the child bicyclist is able to perceive the hazard instigator (overt hazard) in the first level of situation awareness (perception). In the second level of situation awareness (comprehension), the child bicyclist attempts to make an interpretation of the on-going situation. At last, the child bicyclist makes a prediction regarding how the situation might develop in the third level of situation awareness (projection), decides whether the situation requires anticipation and select an evasive or braking action in order to avoid collision. Covert hazards on the other hand require more elaborated experience as the hazard is often not directly visible in the environment. Thanks to more elaborated schemata resulting from extensive experience and knowledge in a wide variety of traffic situations, adult bicyclists are able to perceive, comprehend and anticipate these hazardous situations in a more automated matter (Vlakveld, 2011). Child bicyclists lack this knowledge and experience of where to look and will therefore often fail to perceive the relevant cues in the environment which might predict a potential danger and miss the opportunity for early anticipation. When the hazard instigator is not present in the environment, for example when a van blocks clear view on pedestrians at a pedestrian crossing (covert hazard), child bicyclists fixate later on the potential hazard and are therefore later to anticipate indeed. The shorter dwell times and fewer fixations on the hazards support our findings that child bicyclists have a poorer understanding of the potential danger within the covert hazards. Since the child bicyclists also demonstrated longer response latencies, shorter dwell times and fewer fixations on the overt hazards compared to the adult bicyclists in the pre-test, post-test and retention-test, it might be assumed that children have a different concept of danger. Thornton et al. (1999) described that for the young children, the main responsibility is *not to damage things* while the older children approach traffic from the perspective of *not make the kind of mistakes that could lead to an accident.* Furthermore, when children primarily focus on the salient overt hazards they will fail to focus on other less salient characteristics in the environment that also might cause a threat to the bicyclist (e.g. a couple of parked cars that block view on intersecting streets).

As for the intervention, child bicyclists detected up to 5.1% more covert hazards in the post-test and decreased their response latencies to the covert hazards with 407ms compared to the pre-test. Our findings therefore concur with van Schagen and Brookhuis (1994) who demonstrated that traffic education has a very strong short-term effect on children and with Isler et al. (2009) who reported comparable improvements in hazard perception skill of learner drivers after a brief intervention. In addition, children tended to fixate sooner on the covert hazards in the post-test and the retention-test with respect to the adult bicyclists and increased their dwell time and number of fixations on the covert hazard towards the retention-test suggesting that child bicyclists are more aware of and vigilant to the potential dangers in traffic. In support of our findings, Fisher et al. (2006) and Vlakveld (2011) reported similar improvements in the number of glances on the hazard in trained learner drivers. A better understanding of the covert hazards in child bicyclists might imply better situation awareness in which early and accurate decision-making relies on the formation of internal models or schemata that are stored and can be recalled from long term memory stores. These schemata contain prototypical information in a wide variety of traffic situations and facilitate more automated decision-making. A hazard perception training in child bicyclists will attempt to improve their ability to perceive and extract the relevant visual information in the environment, interpret and integrate this information into a holistic perception of the situation and make a corresponding projection of how the situation might develop in the future. Hazard perception is, in other words, primarily driven by top-down attentional control, which refers to the higher cognitive processes that guide our attention to the task-relevant information in the environment rather than bottom-up attentional control (Chapman and Underwood, 1998).

The beneficial effect of the intervention, unfortunately, somewhat reduced three weeks later. In contrast to more experienced adult bicyclists, this knowledge and experience from the intervention, has not yet been transferred to long term experience given that response latencies for the covert hazards increased again on the retention-test. The training period was too short to improve child bicyclists' reaction times and visual behaviour towards the level of adults. Improving hazard perception in children might therefore require more extensive training. Even though Meir et al. (2015b), for example described only one session of 40 min to be effective for short-term improvements in child pedestrian perceptual skills, Schwebel and Mcclure (2010), and Schwebel et al. (2016, 2013) on the other hand, recommended a minimum of six to eight training sessions of at least 20–30 min/session to consolidate long-term learning experiences which is in concordance with the power law of practice. Mckenna and Farrand (1999) pointed out that automaticity might develop quickly in the lab indeed, but might take years to develop in real-world tasks. Given the complexity of bicycling, bicycling training should contain exercises that focus on the development of motor cycling skills, acquiring sufficient skills to interpret and anticipate dangerous situations and to improve knowledge and attitudes in traffic. Furthermore, training must also comprise a number of sessions where these separate skills are combined such as on-road bicycling trips under adult supervision. The importance and magnitude of bicycle training should therefore be considered a lifelong engagement.

Like any study, the current study suffers certain limitations and some considerations need to be made. At first, children's natural development of cognitive function and the visual system might act as a constraint for the uptake of the relevant visual information (Zeuwts et al., 2017a). Spatial and temporal accuracy of saccades, the functioning of working memory or the ability to sustain attention and predictive control all develop into adolescence as function of maturation of the central nervous system indeed (Kowler, 2011; Land, 2006; Langaas et al., 1998; Meir et al., 2013; Robert et al., 2014). Nevertheless, a vast amount of research demonstrated that hazard perception does not utterly rely on the development of the visual and cognitive functioning, but on experience too (Ampofo-Boateng and Thomson, 1991; Chihak et al., 2014; Meyer et al., 2014; Oron-Gilad et al., 2011; Schwebel et al., 2016; Schwebel and Mcclure, 2010; Zeuwts et al., 2017a,b). Second, given that the current study compared children to adults but did not include a control group and only reported a rather limited sample size the results should be interpreted with caution as these limitations might introduce some error. Future research should therefore consider including larger sample sizes with children of different ages and skill levels, from more different regions (urban, city,…) together with a control group for comparison. Third, participants might have displayed more risky behaviour since they realized nothing could happen (Meir et al., 2013) since the they could not get hurt when they would collide with a car or another traffic participant. This might have caused differences in children's motivation and behaviour when presented with the hazard perception test (Fuller et al., 2008; Schwebel et al., 2016). Lastly, also the content of the video clips and the way of presentation should be considered. For example, the nature of the covert hazards that might have been to salient as they often resulted in an imminent threat together with the relatively small screen of the test PC, which does not require extensive scanning patterns could partially explain the lack of a more pronounced difference between children and adults. Bicycling in real-life is a much more demanding task, which requires the bicyclist to search and identify potential hazards, decide whether the situation is dangerous or not and adapt riding behaviour accordingly. Factors such as stress, arousal, distraction, fatigue or familiarity with the neighbourhood all affect the bicyclists' decision but remain difficult to replicate in the lab. A bicyclist will, for example, probably not devote one hundred per cent of his time to hazard perception but might be distracted by a dog barking, a friend passing by or just finding himself in a dreamy state. Diversion of attention from the cycling task has been suggested to contribute to traffic accidents and especially children might encounter difficulties with hazard perception when they are distracted as their perceptual skills are often not automated yet (Wood et al., 2016). While this might partially explain the relative small differences in response rate between children and adults, future research should consider presenting participants with scenarios of a longer duration (e.g. 3 min) in which the participant receives the instruction to bicycle from one location to another and behave as naturally as possible instead of tracking down all possible hazards. Furthermore, the current hazard perception test contained video clips of typical Belgian traffic environments which might not be representative for traffic settings in other countries without adjustments. It would be interesting to replicate the current research in other countries with a different bicycle culture. Lastly, even though video clips in the hazard perception test were presented in randomized order and test occasions were separated by two or three weeks, our results might be confounded, as the video clips for each occasion were the same. Although this is suggested to be sufficient time (Zeuwts et al., 2017b), it is recommended that hazard perception interventions might include different clips for the pre, post and retention-test.

Based on the limitations and recommendations the use virtual reality can be advocated as the most effective strategy for testing and training hazard perception in child bicyclists. It allows for repeated unsupervised practice without risk of injury, automated feedback on success or failure, tailoring the test and training to skill level of the child, offers an appealing environment and most recently given technological advances, potential for broad dissemination using mobile smartphone technology. Together with a VR glasses and a mounted bicycle, it offers the possibility to maintain the perception-action coupling while being immersed in traffic (Schwebel, 2017).

5. Conclusion

In the context of life-long traffic education, the current study focussed on improving child bicyclists' hazard perception skills by means of a brief hazard perception training intervention. Thanks to the intervention, the child bicyclists improved their situation awareness and hazard perception for covert potential hazards on the post-test even though the training period was too short to improve towards a level comparable to adults.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.aap.2018.02.006.

References

Ampofo-Boateng, K., Thomson, J.A., 1991. Children's perception of safety and danger on the road. Br. J. Psychol. 82, 487–505.

Borowsky, A., Shinar, D., Oron-Gilad, T., 2010. Age, skill, and hazard perception in driving. Accid. Anal. Prev. 42, 1240–1249.

Briem, V., Radeborg, K., Salo, I., Bengtsson, H., 2004. Developmental aspects of children's behavior and safety while cycling. J. Pediatr. Psychol. 29, 369–377.

Carpentier, A., Nuyttens, N., 2013. Jaarrapport Verkeersveiligheid 2011: Analyse van de

verkeersveiligheidsindicatoren in Vlaanderen tot en met 2011 [Annual Report of road safety 2011: Analysis of road safety indicators in Flanders until 2011]. Brussel.
Chapman, P.R., Underwood, G., 1998. Visual search of driving situations: danger and experience. Perception 27, 951–964.
Chihak, B.J., Grechkin, T.Y., Kearney, J.K., Cremer, J.F., Plumert, J.M., 2014. How children and adults learn to intercept moving gaps. J. Exp. Child Psychol. 122, 134–152.
de Hartog, J.J., Boogaard, H., Nijland, H., Hoek, G., 2010. Do the health benefits of cycling outweigh the risks? Environ. Health Perspect. 118, 1109–1116.
Deery, H.A., 1999. Hazard and risk perception among Young novice drivers. J. Saf. Res. 30, 225–236.
DEKRA Automobil GmbH, 2011. Road Safety Report 2011 – Pedestrians and Cyclists. DEKRA Automobil GmbH, Stuttgart.
Ducheyne, F., De Bourdeaudhuij, I., Lenoir, M., Cardon, G., 2013a. Does a cycle training course improve cycling skills in children? Accid. Anal. Prev. 59, 38–45.
Ducheyne, F., De Bourdeaudhuij, I., Lenoir, M., Spittaels, H., Cardon, G., 2013b. Children's cycling skills: development of a test and determination of individual and environmental correlates. Accid. Anal. Prev. 50, 688–697.
Duchowski, A.T., 2007. Eye Tracking Methodology: Theory and Practice, second. ed. Springer, London.
Ellis, J., 2014. Bicycle Safety Education for Children From a Developmental And Learning Perspective (Report No. DOT HS 811 880). Washington DC.
Endsley, M.R., 1995. Towards a theory of situation awareness in dynamic systems. Hum. Fact. 37, 32–64.
European Commission, 2015. Traffic Safety Basic Facts on Cyclists 2015.
Fisher, D.L., Pollatsek, a P., Pradhan, a, 2006. Can novice drivers be trained to scan for information that will reduce their likelihood of a crash? Inj. Prev. 12 (Suppl. 1), i25–i29.
Foot, H.C., Tolmie, A., Thomson, J., Mclaren, B., Kirstie, W.W., Whelan, K., 1999. Recognising the hazards. Psychologist 12, 400–402.
Fuller, R., McHugh, C., Pender, S., 2008. Task difficulty and risk in the determination of driver behaviour. Rev. Eur. Psychol. Appliquée/Eur. Rev. Appl. Psychol. 58, 13–21.
Gugerty, L., 2011. Situation awareness in driving. In: Fisher, D.L., Rizzo, M., Caird, J.K., Lee, J.D. (Eds.), Handbook of Driving Simulation for Engineering, Medicine, and Psychology. CRC Press, pp. 265–272.
Gugerty, L.J., 1997. Situation awareness during driving: explicit and implicit knowledge in dynamic spatial memory. J. Exp. Psychol. Appl. 3, 42–66.
Hill, R., Lewis, V., Dunbar, G., 2000. Young children's concepts of danger. Br. J. Dev. Psychol. 18, 103–119.
Holmqvist, K., Nyström, M., Andersson, R., Dewhurst, R., Jarodzka, H., van de Weijer, J., 2011. Eye Tracking: A Comprehensive Guide to Methods and Measures, first. ed. Oxford University Press.
Huestegge, L., Skottke, E.-M., Anders, S., Müsseler, J., Debus, G., 2010. The development of hazard perception: dissociation of visual orientation and hazard processing. Transp. Res. Part F: Traffic Psychol. Behav. 13, 1–8.
Isler, R.B., Starkey, N.J., Williamson, A.R., 2009. Video-based road commentary training improves hazard perception of young drivers in a dual task. Accid. Anal. Prev. 41, 445–452.
Kowler, E., 2011. Eye movements: the past 25 years. Vis. Res. 51, 1457–1483.
Land, M.F., 2006. Eye movements and the control of actions in everyday life. Prog. Retin. Eye Res. 25, 296–324.
Langaas, T., Mon-Williams, M.P., Wann, J., Pascal, E., Thompson, C., 1998. Eye movements, prematurity and developmental co-ordination disorder. Vis. Res. 38, 1817–1826.
Maring, W., van Schagen, I., 1990. Age dependence of attitudes and knowledge in cyclists. Accid. Anal. Prev. 22, 127–136.
Mckenna, F.P., Farrand, P., 1999. The role of automaticity in driving. In: Grayson, G.B. (Ed.), Behavioural Research in Road Safety IX1. Transport Research Laboratory, Crowthorne, pp. 20–25.
Meir, A., Borowsky, A., Oron-Gilad, T., 2014. Formation and evaluation of act and anticipate hazard perception training (AAHPT) intervention for young novice drivers. Traffic Inj. Prev. 15, 172–180.
Meir, A., Oron-Gilad, T., Parmet, Y., 2015a. Are child-pedestrians able to identify hazardous traffic situations? measuring their abilities in a virtual reality environment. Saf. Sci. 80, 33–40.
Meir, A., Oron-Gilad, T., Parmet, Y., 2015b. Can child-pedestrians' hazard perception skills be enhanced? Anal. Prev. 83, 101–110.
Meir, A., Parmet, Y., Oron-Gilad, T., 2013. Towards understanding child-pedestrians' hazard perception abilities in a mixed reality dynamic environment. Transp. Res. Part F: Traffic Psychol. Behav. 20, 90–107.
Meyer, S., Sagberg, F., Torquato, R., 2014. Traffic hazard perception among children. Transp. Res. Part F: Traffic Psychol. Behav. 26, 190–198.
Oja, P., Titze, S., Bauman, a, de Geus, B., Krenn, P., Reger-Nash, B., Kohlberger, T., 2011. Health benefits of cycling: a systematic review. Scand. J. Med. Sci. Sports 21, 496–509.
Oron-Gilad, T., Meir, A., Tapiro, H., Borowsky, A., Shinar, D., 2011. Towards Understanding Child Pedestrian's Deficits in Perceiving Hazards When Crossing the Road. Be'er Sheva, Israël.
Plumert, J.M., Kearney, J.K., Cremer, J.F., Recker, K.M., Strutt, J., 2011. Changes in children's perception-action tuning over short time scales: bicycling across traffic-filled intersections in a virtual environment. J. Exp. Child Psychol. 108, 322–337.
Pradhan, A.K., Fisher, D.L., Pollatsek, A., Fisher, L.D., 2005. The effects of pc-based training on novice drivers' risk awareness in a driving simulator. Proc. Third Int. Driv. Symp. Hum. Factors Driv. Assessment, Train. Veh. Des., vol. 1, 81–87.
Pradhan, A.K., Pollatsek, A., Knodler, M., Fisher, D.L., 2009. Can younger drivers be trained to scan for information that will reduce their risk in roadway traffic scenarios that are hard to identify as hazardous? Ergonomics 52, 657–673.
Robert, M.P., Ingster-Moati, I., Albuisson, E., Cabrol, D., Golse, B., Vaivre-Douret, L., 2014. Vertical and horizontal smooth pursuit eye movements in children with developmental coordination disorder. Dev. Med. Child Neurol. 56, 595–600.
Rosenbloom, T., Mandel, R., Rosner, Y., Eldror, E., 2015. Hazard perception test for pedestrians. Accid. Anal. Prev. 79, 160–169.
Schaefer, S., Krampe, R.T., Baltes, P.B., 2008. Age differences between children and Young adults in the dynamics of dual-task prioritization: body (balance) versus mind (memory). Dev. Psychol. 44, 747–757.
Schwebel, D.C., 2017. Using smartphone technology to deliver a virtual pedestrian environment: usability and validation. Virtual Real. 21, 145–152.
Schwebel, D.C., Combs, T., Rodriguez, D., Severson, J., Sisiopiku, V., 2016. Community-based pedestrian safety training in virtual reality: a pragmatic trial. Accid. Anal. Prev. 86, 9–15.
Schwebel, D.C., Mcclure, L.A., 2010. Using virtual reality to train children safe street-crossing skills. Inj. Prev. 16, e1–e5.
Schwebel, D.C., Ph, D., Davis, A.L., Neal, E.E.O., 2013. Child pedestrian injury: a review of behavioral risks and preventive strategies. Am. J. Lifestyle Med. 6, 292–302.
Taylor, T.G.G., Masserang, K.M., Pradhan, A.K., Divekar, G., Samuel, S., Muttart, J.W., Pollatsek, A., Fisher, D.L., 2014. NIH Public Acces. Long Term Effects of Hazard Anticipation Training on Novice Drivers Measured on the Open Road.
Thomson, J., Tolmie, A., Foot, H., Whelan, K.M., 2005. Influence of virtual reality training on the roadside crossin judgements of child pedestrians. J. Exp. Psychol. 11, 175–186.
Thornton, S., Pearson, A., Andree, K., Rodgers, N., 1999. Taking the child's perspective seriously. Psychologist 12, 393–394.
Underwood, G., Ngai, A., Underwood, J., 2012. Driving experience and situation awareness in hazard detection. Saf. Sci. 1–7.
van Schagen, I.N., Brookhuis, K.A., 1994. Training young cyclists to cope with dynamic traffic situations. Accid. Anal. Prev. 26, 223–230.
Vlakveld, W., 2011. Hazard Anticipation of Young Novice Drivers. SWOV, Hilversum.
Wetton, M.A., Hill, A., Horswill, M.S., 2011. The development and validation of a hazard perception test for use in driver licensing. Accid. Anal. Prev. 43, 1759–1770.
Wood, G., Furley, P., Wilson, M.R., 2016. Working memory capacity, visual attention and hazard perception in driving. J. Appl. Res. Mem. Cognit.
Zeuwts, L., 2016. Understanding and Stimulating the Development of Perceptual-motor Skills in Child Bicyclists. Ghent University.
Zeuwts, L.H.R.H., Vansteenkiste, P., Deconinck, F.J.A., Cardon, G., Lenoir, M., 2017a. Hazard perception in young cyclists and adult cyclists. Accid. Anal. Prev. 105, 64–71.
Zeuwts, L.H.R.H., Vansteenkiste, P., Deconinck, F.J.A., Cardon, G., Lenoir, M., 2017b. Hazard perception training in young cyclists improves early detection of risk: a cluster-randomized controlled trial. Accid. Anal. Prev. 53, 1689–1699.