School of Transportation Sciences

Master of Transportation Sciences

Master's thesis

Investigating cycling behavior among children with the bicycle simulator

Daria Sergeeva

Thesis presented in fulfillment of the requirements for the degree of Master of Transportation Sciences, specialization Transport Policy and Planning

SUPERVISOR :
Prof. dr. Davy JANSSENS

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PREFACE

“It is better to prevent rather than cure”- Desiderius Erasmus (Dutch philosopher, around 1500 year). This expression can be applied to many fields of life. Especially, it is becoming popular now, with the developing world and appearance of modern technologies. People started to think about healthy, full of emotions and nice life. With the appearance of electronic cars, people think more about environment and prevention of traffic accidents. Now on the first place comes out safety and health of human. For instance, Boston’s vision zero is aimed on reducing traffic accidents and increasing traffic safety. Another example is related with autonomous vehicles, which are actively developing, new detectors are setting down to provide total safety as for passengers as well for road participants.

Many technologies go on the top to provide safety circumstances on the road. Thus, some researchers are figuring out how to do the construction of roads better, another are busy with adjusting special equipment to provide safer environment. However, speaking of cycling behaviour, it is still a blind spot. First, people have some similar patterns, but depending on the situation, behaviour can be changed. Many factors of human being have influence on behaviour, which can be mental fatigue, physical tiredness, emotional side, experience or other factors. It is hard to predict the result of behaviour in some situations, because of people’s diversity.

However, the more we will investigate, the more insights in human behaviour will open. We think that it can be applied as well for cycling behaviour investigation. Hence, when the reasons and hidden processes will be found, many insights of cycling behaviour will be discovered. It might be a chance that hidden processes will help to prevent traffic accidents with cyclists and help to understand reasons and correlation between lapses on road and behaviour. As road accidents can have damage effect for all traffic participants, it is better to investigate deep processes and interconnection to prevent any chance of unsafety, especially for small road users, as children and teenagers.

SUMMARY

This study is about investigation of cycling behaviour. As children, is the most vulnerable group of road users, it was decided to figure out the common behaviour patterns and its correlation between age, gender and other traffic factors. According to the literature, some factors risky behaviour, speed, traffic rules compliance have connection with age and gender. The work was divided into 2 parts: experiment with bicycle simulator and post-questionnaire. The simulation contained events, analyzing of which, it was revealed connection between some factors. 2 events, as giving priority to car and giving priority to pedestrian were excluded from the further analysis due to incorrect recording of data. The other events, as full stop at signs "STOP", full stop at traffic light (changing orange), crashes into cars and pedestrians were taken for analyzation. The second part of experiment was post-questionnaire, which was aimed to figure out any symptoms of sickness after simulation, realism questions and self-reaction estimation.

For statistical analysis was used IBM SPSS Statistics, and it was revealed that age is correlated with stopping distance at orange light, and with full stop at "STOP" sign. The last factor, which was discovered, that those participants who were experienced with crashes by bicycle in past 3 years, also had accidents in simulation with cars. In general, gender didn't affect any factors, however the age had strong relation. Our findings were testified to other literature.

Only a few people had sickness symptoms in simulation, perhaps it is due to first experience of simulation and simulated environment. However, in general children felt well. Realism answers are correlate with the literature output. Thus, no difference in perception of simulation's realism.

Although, the results were valuable, some limitations were highlighted. First, is Bluetooth connection, which sometimes lost, and therefore, there was a chance that a few data were recorded incorrectly. In case of prevent statistical uncertainties and mistakes, the outliers were excluded.

Only a few research questions were proven after analyzing the data, and the rest weren't confirmed. The received output might be very useful for current researchers and government, who are aimed to improve traffic situation and traffic safety of all road users.

Despite there are already some studies, which are considering traffic design, learning games, and new bicycle equipment, our study might be the last piece of puzzle, with which the traffic safety can be improved.

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LIST OF ACRONIMS

Acronym	Meaning
CBQ	Cycling behaviour questionnaire
DBQ	Driving behaviour questionnaire
HMD	Head-mounted display
HTC Vive	Virtual reality brand of HTC Corporation
HUD	Head Up Display
VE	Virtual environment
VR	Virtual reality
SDLP	Standard Deviation of the Lateral Position

1 INTRODUCTION

1.1 Research background

With the new century and fast developing world, people started to think more carefully about environment and new technologies which can help to reduce emissions and pollution. For instance, in Brussel and some other cities of Belgium were introduced a set of rules, which allows to enter the cities with the modern cars, that have less emissions and new type of engine. Several steps were made to improve the situation. Some technologies as electric cars are actively used in the present; however, some are developing.

Urban mobility shares 3 types of transport: collective, individual and freight (Rodrigue, 2020). Individual transport can be car or bicycle. For the short distances and for walk purposes people usually prefer to use bicycle or just simple walk. As Belgium is a country of cycle racing, the most popularity has bicycle. People use it everywhere: for sport reasons, for leisure or for destination trips as house-work and house-school (university). The main advantages of this transport: it keeps your body healthy, in case of traffic congestion it helps for the short routes, it doesn't need to be charged by electricity or fuel, thus the maintenance of bicycle is much lower than, for instance, the car.

As a cycling has most popularity, the bicycle infrastructure in Belgium is actively developing (Wegman, Zhang, Dijkstra, 2012): there are new cycle paths building, some of them are renovating (where were unseparated routs with the car traffic, there are appearing new, which remoted from daily car traffic) (Ducheyne et al, 2014). However, not only adults ride by bicycle on the daily base, but also children, who as well use bicycle to reach school and home. Thus, some hazards and different dangerous situation might take place. Children, who tend to behave risky or teenagers who ride a bicycle with less situational awareness can easily miss some hazards or make mistakes, which lead to near-misses, accidents and even injuries. As an example, the study of Israel researchers revealed that from the hospitalized patients (5529 people), the children rate is 3764 persons, while injured adults were only 1765. All these cases were related with the bicycle injuries and with a motorized vehicle involvement (Siman-Tov et al., 2012). In other words, cyclists have a relatively high accident rate compared to car drivers and pedestrians and for one car accident there are 150 cyclists in car-bike accidents (Wegman, Zhang, Dijkstra, 2012).

Other studies showed that the number of cycle injuries among teenagers (13-15 years old) is 981 by males and 435 by females, while 16-19 years old boys and girls had 1723 and 900 accidents respectively (Taniguchi et al., 2022).

Thus, the actively increasing number of cyclists (according to the Bulletin serving Belgium's community only in 2020 was registered 4.6 million bicycle trips in Brussel), more popularity of this mode and risk of traffic cases (as near-misses, lapses, injuries and fatalities), create a necessity for the investigation of cycling behaviour among children.

1.2 Research area

Participants, which was asked to come for experiment (see Methodology part) were from Hasselt, thus the main research area is Hasselt. Hasselt is one of the cities of Limburg province, and its boarders are Diepenbeek on the East, Lummen on the West, Zonhoven on the Nord, and Alken on the South. In 2020 in Hasselt are recorded 79 743 citizens (Hasselt in cijfers). On the map (fig.1) Hasselt is reflected on blue area (Limburg area).

FIGURE 1 Parts of Belgium (google images)

49 % of citizens are men, and 51 % women, where 6 – 11 years old are 4 681 people, 12 – 17 years old are 4 532 persons. In total 10 981 school students attend the secondary education. However, there are no statistics information how many children from 11 to 15 years old ride bicycle, but there is information about total cycle length, which is 43 830 m.

1.3 Problem statement

There is much research have been done to improve bicycle network. However, most of them is considering cycling infrastructure, as widening cycle line, doing the smart bicycle pass, so the cyclist can indicate the gap for crossing, looking to traffic through walls (traffic augmentation), displaying the warning signs at Head-Up-Display (HUD) (von Sawitzky et al., 2020). Another way is to improve the structure of bicycle, as add additional complements: visual and tactical signals to handlebar, tactical for saddle and audio for helmet (Matviienko et al., 2018).

However, technical aspects are a part of the solution to improve bicycle network and reduce number of accidents, near misses and injuries among cyclists. There are another side of problem, which is cycling behaviour. Although, some researches have been done to investigate cycling behaviour, they are mostly were aimed on adults. For instance, Useche and colleagues (2021) have developed cycling behvaiour questionnaire (CBQ) for investigation of adults' behaviour. Elliott and Baughan have developed a Child

Road Behaviour Questionnaire (CRBQ) (2003), and Adolescence Road Behaviour Questionnaire (ARBQ) (2004). However, mostly it is aimed for pedestrians and only few questions related to riding a bicycle.

Thus, here appears a problem, which is insufficient number of studies dedicated to children, which leads to lack of information in children's cycling behaviour. Secondly, for riding a bicycle people don't need driving license, and nobody can check, whether cyclists ride carefully and within the rules. It means, that traffic offences can be hardly followed. Additionally, if traffic offences did not lead to serious injuries, which require hospital intervention, but only to near misses or light injuries, they are not statistically recorded. Thus, understudied problem, no driving license, no control in traffic offences and hardly gained data are the reasons of investigation of children cycling behaviour. "It is better to prevent rather than cure"- Desiderius Erasmus (Dutch philosopher, around 1500 year).

1.4 Research objectives

The research objectives are:

- Find literature, which studies cycling behaviour;
- Highlight the main aspects, which might be leading factor of cycling accidents, traffic offences;
- Describe the working process of bicycle simulator;
- Emphasize the process of experiment with bicycle simulator;
- Find participants;
- Gain the data from participants and analyze;
- Use SPSS program for analyzation;
- Make a conclusion and emphasize results.

1.5 Research questions

Research questions are linked to objectives and investigate the problem of cycling behaviour among children. Thus, the main research question is "How do children of 11 – 15 years old cycle"? The sub-questions are:

1. Does the age have direct influence on cycling behaviour? Are the older cyclists more careful on roads?
2. Is the gender related with cycling behaviour? Are females tending to cycle more careful than males?
3. Are breaking rules in past 3 years correlate to average speed, traffic rules compliance and crashes in the simulation?
4. Is the stopping distance related to gender or age? Are boys stopping before sign or traffic light closer than girls?
5. Do the participants have simulation sickness? Is it related with gender or age? Are girls have more often symptoms than boys?
6. Do boys and girls find experiment realistic in simulated environment? Is it related with age or gender?
7. Is the general reaction to events in simulation differ between boys and girls? Are boys better in reaction to hazards than girls? Is age related to self-valued reaction?

8. What symptoms of sickness were most common and most strong among boys and girls in each age group?
9. On what event in the simulation girls and boys had better reaction? What event was the most difficult in each age group?

1.6 Thesis outline

The Thesis is divided into several parts: introduction, literature review, methodology, procedure, descriptive analysis, results, discussion, limitations and recommendations. Literature review describes factors, which might influence cycling behaviour, which are risky behaviour, gender and age, experience, traffic rules compliance, near misses. Besides the factors, literature review gives information about structure and functioning of bicycle simulator.

Methodology part explains structure and functioning of UHasselt bicycle simulator, gives information about parts of experiment, which are simulation and post-questionnaire. In this part are given different types of events, which are in simulation, their description and pictures.

Procedure part explains what type of statistics programs were used for analyzation. It is also given information about outliers and specific formulas, which were used to exclude any incorrect data. At the same time, it explains why some variables could not be taken for experiment. It is also listed main statistical coefficients which were used for further analysis.

Descriptive analysis is the main part of Thesis, here are the data which are interpreted in results part. Mainly this part contains statistical coefficients, variables, formulas and description of 0 and 1 Hypothesis.

Results is the part of interpreting analysis from previous paragraph. Here are given main conclusions about experiment and post-questionnaire. Discussion part describes obtained results and compares with the information from literature review, research sub-questions from introduction.

Conclusion shows general results and overview of accomplished work. Limitation gives a short description of appeared problems during experiment. And the last, recommendation part gives thoughts and ideas for future research.

Appendix contains information about questions in CBQ in Dutch, and studies where were used bicycle simulator with description of purposes.

2 LITERATURE REVIEW

2.1 Influencing factors on the cycling behaviour

There were many hypotheses, which were aimed to solve the problem of risky behaviour of adolescences while driving. One of them complains, that in the pubertal period teenagers are trying to reach out their personal frames to set their independence. Although they try to figure out the behavioural frames, there is a probability, they could not recognize potentially dangerous situations. As a consequence, adolescences may do attempts to find risky situations on purpose (Feenstra et al., 2010).

Other authors list several factors, which explain the reasons why adults tend to behave less risky in the traffic conditions, than teenagers. There are some factors as: behaviour characteristics as experience; brain evolution; level of aggression; personal characteristics as hostility; demographic (less control from adults); peer influence (Shope, Bingham, 2008).

The map (Fig.2) below reflects the most common factors, which contains cycling behaviour. All these experiments and theory was tested on bicycle simulator. Thus, we have a detailed schema about behaviour aspects of cycling. Something influences directly as distractor on the road: for instance – the opened car's door or the maneuver from the front car. Chatting or calling people while cycling can be considered as direct factors as well. However, the type of personality of cyclist or socio-demographical characteristics are influencing not obviously, and the level of influence can be only assumed.

Thus, it was considered many behavior factors which have direct influence on the road behaviour. The described aspects are represented in the schema (Fig. 2) and structured by groups.

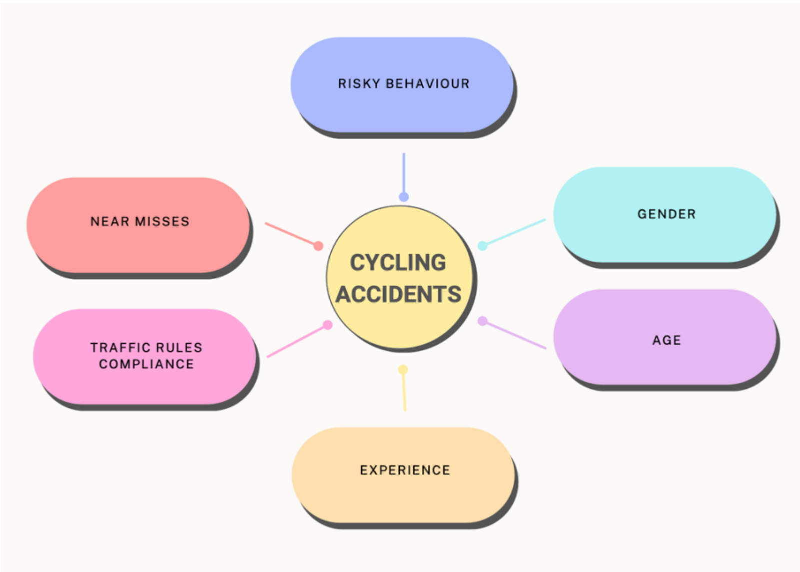

FIGURE 2 Overview of the possible cyclist's accident aspects based on literature (own elaboration)

2.2 Risky behaviour

Feenstra et al. (2010) have revealed that indicators of attitudes, norms and self-efficacy correlated with intentions and behaviour. Self-efficacy in the field of safe cycling had negative correlation with risky behaviour and intentions of risky cyclists. Participants, who had significant points on personal norms for keeping themselves and others safe, scored lower in risky behaviour while cycling and risky intentions.

However, accidents and near misses had positive correlation with risky behaviour. It explains that adolescences who have more risky style of cycling, are more likely to face near misses and accidents. Additionally, teenagers who had accidents in 2 years, claim about risky behaviour while cycling in terms of last month (Feenstra et al., 2010).

Young male and poor educated male tend to have more risky behaviour and demonstrate bad attitude to safe driving (Nordfjærn, Jørgensen, Rundmo, 2010).

In the earlier studies Iversen and Rundmo (2004) have demonstrated that drivers with less awareness about traffic safety or drivers, who prone to overspeeding and offences, are more likely to behave risky. People with the more risky style of driving usually get into accidents or near-misses. Researchers also figured out that young drivers and male drivers behave more risky than other road users.

The less level of traffic safety attitude has a cyclist, the higher rate of risky behaviour, near misses or accidents he has. It means the cyclists with the lover rate of "social desirability" characteristics have a stronger tendency to "risky driving". As a predictors to risky behaviour the most common factors are knowledge of traffic rules, opinion about them ans about social behaviour, carelessness, hazard awareness (Taniguchi et al., 2022).

Another research approves the factor as well that children with higher levels of aggression, especially 10-year-old boys, who are prone to more risky cycling behaviors (Stevens et al., 2013).

It was revealed that teenagers, who are exposed to higher risk in the traffic conditions, tend to perceive themselves as riskier, less care about their and others road participants traffic safety (Feenstra et al., 2010).

2.3 Gender and age

The young drives have shown a significant correlation between violations and accidents. The rate of accidents including the cyclists in Japan in the teenager age of 13-15 years old was 981 by boys and 435 by girls, in the age of 16-19 years old it was 1723 and 900 for males and females respectively (Taniguchi et al., 2022). Thus, it can be seen, that boys tend to have more road accidents than girls. However, some other research show that girls are more likely to have lapses and do mistakes while driving more frequently (de Winter, Dodou, 2010).

For instance, Stevens et al. (2013) in their research revealed that girls need more time to cross intersection. This study was about investigation of bicycling across traffic-filled intersections in the virtual reality. In total, 52 participants of 10-12 years old and 57 children of 12-13 years old were taking part in the experiment. The fact that girls stuck behind the lead car less tightly and had less time to spare relative to the tail car than boys indicates that gender also plays a role in road crossing behavior. Like younger children, girls appeared to hesitate when starting to drive. 10 years old children with higher inhibitory control had more time between approaching vehicle, rather than children with a lower inhibitory control, while 12 years old did not differ. The older children calculated the time approaching the intersection more precisely and cut more closely the car.

Here can be noticed that it is not only gender may influence the cycling behaviour but as well the age. Specifically, 78.6% of accidents including senior high schoolers and 80.5% accidents with the junior high school students were related with violations. Among age group 12 – 13 years old such factors as risky behaviour, making mistakes, playing dangerously, lack of protective behaviours were predictors to number of accidents and near-misses. However, the results showed that for older age (14 – 16 years old), as a predictor were only mistakes (Taniguchi et al., 2022).

In the similar studies using bicycle simulator Plumert and Kearney (2014) came to the conclusion that children cannot estimate the speed of cars and they orient more to the distance. It was conducted a study with focus group 5-15 years old with the help of virtual reality. Research revealed that more experienced cyclists were the children in the older age. They did not stop or slowed down before the intersection and estimated the gap for crossing while driving. Contrary, children of younger age are more likely stopped before intersection and not always estimated in the right way the gap affordance. Thus, this model of behaviour has led in virtual reality to accidents.

The investigation has showed that older cyclists have significantly lower errors score and lower traffic violation. Young cyclists have smaller values of positive cycling behaviour rather than older people (Useche et al., 2021).

However, while unintended behavior, it was not any gender differences. The authors suppose that errors more related to cycling skill than risk perception and can exist equally within both genders (Useche et al., 2021).

2.4 Experience

Some researchers have reviewed that children perceive road conditions while cycling worse, and realize the hazards less than adults. Adults react on hazards and potentially dangerous moments quicker than children, however the traffic awareness same in both cases. Thus, although the children's perception can be compared with the adult's perception, their comprehension can absent whether experience of real-world experience (additionally of driving experience), which consequentially impairs their ability to predict the future situations (Vansteenkiste et al., 2016; de Geus et al., 2020).

Other studies used the gamification method to test 8-9 years old children for the hazard's perception. The main aim for participants was to watch the cycling videos (captured from the cyclist view) and figure out potentially hazards or hidden dangers. For the right answers the points were awarded. In case of participant reacted late on the hazards or answered incorrectly, the feedback was given. This investigation was conducted before and after learning intervention. Although children reacted faster after learning intervention, their sensibility to potentially or hidden hazards did not change in comparison with adults. Adults surpassed youngsters in both cases: game task and situational awareness test (Lehtonen et al., 2017b).

Children may overestimate their experience of cycling, which can be used to understand them: It was assessed higher level cycling skills in 11–13 years old cyclists using a set of computer tests which simulate traffic costs and coverage of hazard perception components. A third of participants tolerated at least half of all hazards, highly rated intersection and worst propagation in difficult scenarios, although most of them agreed with the statement "I'm an experienced cyclist" (Twisk et al., 2018).

Bishop et al. (2022) have conducted the experiment on the bicycle simulator with children to reveal results of intervention. Children were divided into 2 groups randomly: control and intervention. They were tested on level of awareness to predict potential hazards. Control group did not receive any behaviour interventions. However, the intervention group has shown better results in the level of awareness and predicting hazards rather than control group. Thus, the experience of intervention group became higher than experience of control group, and children did less mistakes while cycling.

Robbins and Chapman (2018) have revealed that drivers, who have current cycling experience figure out the potentially hazards and consider different aspects of traffic situations better while driving, rather than people who do not have cycling experience. In investigation have participated 20 drivers with no cycling experience and 22 drivers with cycling experience. The main task was to find out the changing object in the simulation experiment. The changing object was either the traffic sign, car, pedestrian, or cyclist.

In investigation, which consider drivers, was also claimed that drivers with the higher level of experience reported about less risky behaviour while driving. For instance, in China was conducted the same experiment and the conclusions confirmed results: higher self-reported driving efficiency is associated with safer driving behavior (Martinussen et al., 2014; Xu et al., 2018).

Considering the CBQ (cycling behaviour questionnaire) the strongest connection was between errors and cycling experience. Thus, participants, who estimated themselves as more experienced, reported about less memory or attention errors while cycling. It consistent the results of DBQ (driving behaviour questionnaire), which revealed that people who tend to have more experience, make less mistakes while driving (McIlroy et al., 2022).

2.5 Traffic rules compliance

In some articles are mentioned as a behavioral aspect the way of crossing intersection. Heinovski et al. (2019) researched different types of road crossing scenarios in the virtual reality. The bellow given figure describes the most frequent cases of accidents. The motorized vehicle is defined on the Figure 3 as "car sign" and the cyclist as "cycle sign" respectively.

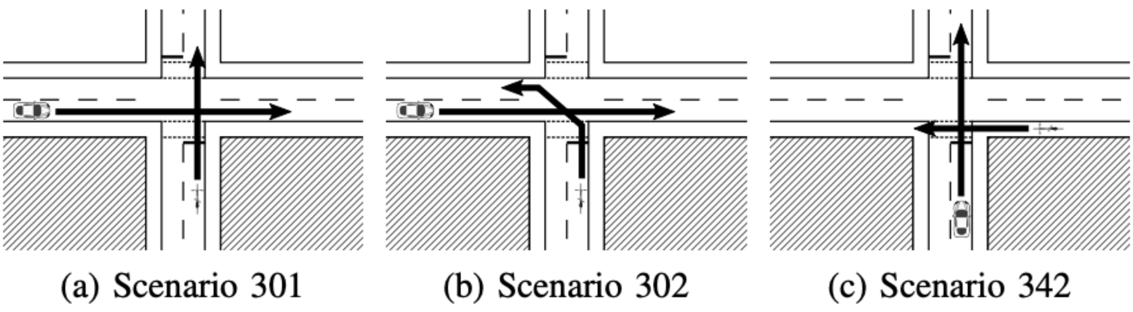

FIGURE 3 Different types of scenarios with high number of accidents involving a motorized vehicle and a cyclist (Heinovski et al., 2019)

The Scenario 301 is the most frequent case with the accidents which occurs through the fault of children. This situation takes 3rd place among all accidents with the motorized vehicle and children. In this scenario cyclist arrives at the intersection from the South and should give the priority to the vehicles approaching the main road from West or East sides. The most common mistake here is that cyclist does not want to yield to car and starts to cross intersection without any waiting (Heinovski et al., 2019).

The Scenario 302 describes the similar situation as the previous one, but with the small difference that cyclist turns left from the South side. This case is complicated with the building from the left side, which closes the line of vision. Thus, the cyclist not only does not give priority to car, but also does not see it (Heinovski et al., 2019).

The Scenario 342 (Figure 3, Figure 4) is the most common situation according to the accidents; thus, it is the most dangerous. In this case cyclist arrives to the intersection from the East side. Moreover, it rides on the wrong side of road (from the opposite side). In this case car driver wants to continue to ride as well as cyclist. The car should give the priority to bicycle. However, the right-side building and the wrong direction of cyclist close the line of vision. Thus, it occurs an accident (Heinovski et al., 2019).

FIGURE 4 Cyclist drives the wrong direction of road (google images)

2.6 Near misses

Let us describe other distractors while cycling and their influence on behaviour. Aldred (2016) in her article defines cycling experience in the near misses. Experience of near misses is valuable because in the future cases it gives the signals to prevent accidents.

This research discusses different types of near misses in the Great Britain. The description of accidents was divided into 8 different highlights. The most frequent was the way blocked (common requires the turn), problematic overtaking with the vehicle, which occurs suddenly on the way of cyclist. Together they created 80% of cases (Aldred, 2016). All near misses are described in the Figure 5.

Category	Description	Number	Percent of all incidents	Percent of incident type judged as 'very scary'	Approx. frequency, annual[a]
BLOCK	Cyclist's way blocked	1506	37.7	6.2	170
PASS	Problematic pass (usually too close)	1169	29.3	22.0	130
PULL	Vehicle pulls out or in across cyclist	644	16.1	16.4	70
DRIVEAT	Person drove (or cycled) at cyclist head on	255	6.4	17.3	30
HOOK	Road user turns across cyclist's path	215	5.4	22.0	25
OTHER	Other incident	107	2.7	7.5	10
TAILGATE	Tailgates cyclist without passing	72	1.8	18.1	<10
DOOR	Opens car door in cyclist's way	26	0.7	23.1	<10
		3994 (total)	100 (total)	14.4% (mean)	450 (total)

[a] Assuming a regular commuting cyclist, riding 2500 miles per year.

FIGURE 5 Incidents frequency (Aldred, 2016)

Between 1985 and 1982 in London was recorded 21.8% cyclists' death which were caused by motorized vehicle did overtaking through the cyclists. According to the Great Britain statistical data, the too close distance between vehicle and cyclist led to 19% death of last one (Aldred, 2016).

The frequently happening situation which causes the injuries of cyclists as well, is when vehicle crosses or pulls out the bicycle line (Figure 6). It can happen at intersections either when busses pulling into stops or taxis pulling out (Aldred, 2016).

FIGURE 6 Car is pulling out the cycle lane (google images)

The next type of accidents is when cyclists was hit by a car on the narrow or residential streets (Figure 7), where driver is expecting to be given a first priority. However, the injuries were not harmful. Perhaps it is related with low speed of car on such road sections (Aldred, 2016).

FIGURE 7 Narrow residential street and cyclist (google images)

For the dead or seriously injured cyclists from the age 25 to 39 years old the 10 most frequent factors contributing the cyclist behaviour were: lack of the proper road vision, failure to judge another's path or speed, poor turning or maneuvering, inattention/nonsense/rushing, loss of control, riding off the sidewalk, wearing dark clothing at night, riding through an intersection, failure to obey yield or stop signs, and lack of lighting devices at night or when visibility was poor (Aldred, 2016).

In the Figure below are represented the factors which led to the accident. Thus, if for instance cyclist waited, it could prevent 626 incidents. However, the cyclist did not follow the certain pattern of behaviour and it was recorded 626 cases which caused the injuries or accidents. As we combine these factors, the most common mistakes are not waiting, not looking and passing (Aldred, 2016).

Characteristic/behaviour	Count	Weighted percentage (% of content related to prevention by others)	Similar words
Waited	626	2.68	Wait, waited, waiting, waits
Looking	428	1.83	Look, looked, looking, looks
Passing	351	1.50	Pass, passed, passing
Stopped	189	0.81	Stop, stopped, stopping, stops
Space	182	0.78	Space, spaces
Slowed	157	0.67	Slow, slow, slowed, slowing, slows
Patient	126	0.54	Patient, patiently
Aware	122	0.52	Aware, awareness
Room	122	0.52	Room
Checked	107	0.46	Check, checked, checking

FIGURE 8 Preventing behaviour patterns (Aldred, 2016)

2.7 Bicycle simulator

Before setting the experiment, it is important to know how the simulator works and how the data can be gained. There are articles, which are considering the detailed functioning of simulated environment. For instance, Dialynas, Happee, and Schwab (2019) are describing the detailed construction of simulator. Thus, the mechanical portion of the simulator consists of three main structural parts. A bicycle roller training base (600 × 400 mm), a square tube (40 × 40 × 1000 mm) used as a steering column, and a rear half of a step-through bicycle frame (54 cm), see Fig. 2. To mount all the structural parts together the following modification are made. The front roller of the base is removed, and a rectangular tube (40 × 20 × 500 mm) is welded as a replacement. In addition, six metal foot pegs (40 × 20 × 500 mm) two at the front, middle and rear are also mounted. The foot pegs are mainly used to increase the vertical distance of the base in respect to ground and also to distribute the load equally to specific areas of the frame. At the steering column a (25 × 500 mm) tube is welded at a 25° angle and at a 40 mm distance from the end of the square tube.

FIGURE 9 Construction of bicycle simulator (Dialynas, Happee, Schwab, 2019)

To allow the rider to interact with a virtual environment and receive realistic handlebar torque feedback from the simulation model a haptic steering device is required. The device must be able to generate realistic torque feedback to enhance rider control and prevent excessive rotation of the handlebars (Dialynas, Happee, Schwab, 2019).

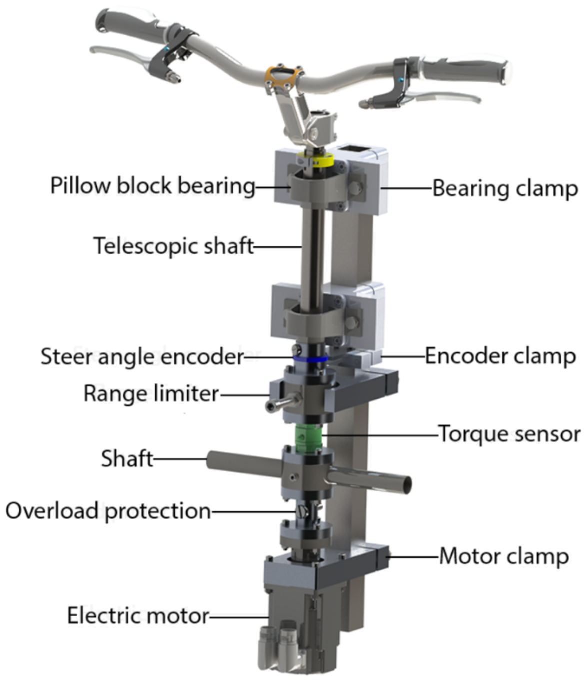

FIGURE 10 Handlebar construction (Dialynas, Happee, Schwab, 2019)

The haptic steering device consists of two sub-assemblies. The steering shaft assembly and the column mount assembly. The steering shaft assembly includes the components used to build the steering shaft, whereas the steering column assembly includes the components used to mount the steering shaft to the column. The steering shaft assembly consists mainly of eight components (not including the handlebar assembly and adaptors). Five of these components are mechanical and three of them are electromechanical. Two pillow block bearings are used to mount the telescopic shaft to the column (Dialynas, Happee, Schwab, 2019).

The simulator is equipped with the visual screens, which stream the simulated bicycle moving. On the screen is also displayed potential hazards, as pedestrian crossing the cyclist's line, blinking traffic lights and others. The handlebar is movable and when the user wants to steer, the HTC Vive trackers, which are set on the handlebar, allow to do it. Positioning of Head-Up-Display (HUD) depends on the angle of user's head. Signals as head transform, speed input, handlebar or body input are using in cave and VR equipment. In the settings the speed of cycling moving can be changed with the mouse movement. For the setting VR equipment, it is used HTC Vive Pro and 4 base stations Vave Index (2 up front and 2 back the bicycle) (von Sawitzky, Grauschopf, Riener, 2020).

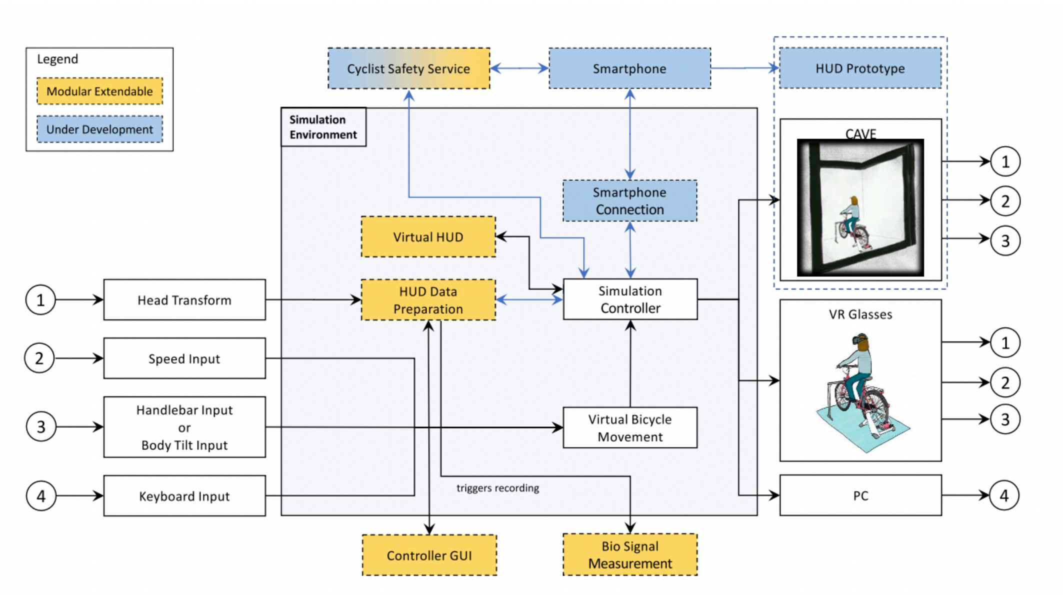

FIGURE 11 Overview of the bicycle simulator (von Sawitzky, Grauschopf, Riener, 2020)

Different instances are distributed by the Simulation Controller. The additional data for the cyclist can be viewed on virtual HUD in the simulation, or in the settings CAVE on the HUD prototype. Controller GUI (Graphical User Interface) allows to choose type of information, which is reflected on HUD and see which output device is used. In addition, it can be selected different conditions and settings for the user's investigation (von Sawitzky, Grauschopf, Riener, 2020).

The technical characteristics of bicycle simulator, which was used for the experiment at UHasselt in the frames of Master Thesis, will be described at Methodology part.

2.8 VR- Realism and sickness

Immersion is a property of a VR system that describes the “extent to which a VR system can support natural sensorimotor contingencies for perception”, while presence is the human response of feeling to be in that environment. Simulator sickness (also sometimes referred to as VR sickness, cybersickness, or visually induced motion sickness) results from a conflict between expected and observed sensory signals. Weech et al. suggest that presence and (cyber)sickness have shared causes and show a negative relationship.

Moreover, motion sickness also depends on the type of visual information presentation, i.e., large display, CAVE environment, or VR, and the availability of auditory cues, or airflow simulation. Low-fidelity simulators can be built with off-the-shelf ergometers. Using such a device, Mittelstaedt et al. demonstrated that participants experienced a lower level of motion sickness with a large display compared to VR glasses (Wintersberger et al., 2022).

Zeuwts et al., 2023 in their investigation have tested children (11-12 years old) on the bicycle simulator in the frames of traffic safety. Participants were in the entire virtual environment (VE), which includes VR lasses. In the sumulation was reflected the typical Belgian city and hazards which might appear while cycling.

The authors conducted the realism questionnaire and simulator sickness questionnaire to estimate the effect from bicycle simulator. Children rated the experiment in VE as “very realistic” (in the Likert scale). Houses, vegetation, streets, cars, cyclists and environmental sounds were varied from “reasonable realistic” to “realistic”. However, only pedestrians in VE were estimated as below “realistic”. Verbal reports of some children suggest that pedestrians’ movement was rather “jerky” compared to real-life. The gender did not show the difference between answers. Thus, participants rated the experiment in VE as sufficiently realistic (Zeuwts et al., 2023).

In the sickness self-reported questionnaire 11 % of participants (130 children overall) claimed to simulator sickness and quitted the test while 1st scenario. Regarding the Likert scale, children did not reported about simulator sickness. In terms of the effects observed related to excessive saliva production, dizziness, and belching, the subjects encountered minimal discomfort. Nevertheless, there were some instances of overall discomfort reported when using the HTC Vive and navigating through the virtual environment. Based on verbal feedback, participants primarily experienced tension and heaviness from the headset, leading to pressure on the head and a heightened sensation of warmth on the forehead where the headset makes contact. Furthermore, no correlation was found between gender and the level of simulator sickness perceived. (Zeuwts et al., 2023).

Achieving an appropriate level of realism is crucial in reducing simulator sickness, as highlighted by Stanislava and Andre (2018). According to self-reported data on simulator sickness, it is observed that nearly one third of the participants experienced mild discomfort while using the bicycle simulator. Additionally, 10% of the participants withdrew from the study due to motion sickness, which aligns with findings from a recent study on simulator sickness in an HMD driving simulator conducted by Malone and Brünken (2021). Qualitative feedback from children indicates that this discomfort primarily stems from the weight, warmth, and tension exerted on the head by the HTC Vive headset. It is worth noting that the duration of the experiment may contribute to the occurrence of motion sickness.

While studies on VR road crossing have reported minimal instances of simulator sickness (Schwebel et al., 2008, 2017), research involving driving simulators often encounter more challenges, including higher attrition rates due to simulator sickness (Agrawal et al., 2017, 2018). In contrast to VR road crossing, where the sense of self-motion is relatively restricted, engaging in virtual biking or driving can lead to an increased discrepancy between the perception of self-motion and the inertial forces sensed by the vestibular system. This disparity may explain why children who withdrew from the study due to simulator sickness frequently mention a heightened susceptibility to experiencing motion sickness in a real car (only based on verbal reports).

The discomfort and nausea experienced could also be attributed to the fixed vertical position of the bike, even during turns, which differs from real-life cycling where riders lean into the curves (Kooijman and Schwab, 2013). This limitation arises from the stationary trainer on which the bike is mounted in the virtual environment. Additionally, the duration of the VR experience, which takes approximately 6 minutes to complete one scenario, may contribute to the heightened level of simulator sickness to some extent.

3 METHODOLOGY

3.1 Experiment

For the more detailed view to the reasons of traffic problems, which involve cyclists, it was decided to arrange the experiment in the laboratory conditions. The experiment is in the virtual reality with the help of cycling simulator. The results of some experiments are showing that participants behave in the same way both in virtual reality and in the real life (van Paridon et al., 2021). This gives reason to assert that experiment results can be reflected and coincided to the real-life conditions.

The bicycle simulator is a bicycle on a stationary platform. All actions, what cyclist makes are joined with the bicycle and reflected to the wall. Thus, with the help of platform and projector the participant doesn't move, but at the same time he can pedaling and see the road around.

The bike simulator incorporates a real bicycle. The rear wheel is connected to a smart trainer device, capturing the rolling motion and speed of the rear wheel, providing a realistic riding experience in terms of pedaling, shifting, and braking. The front fork is connected to a steering motor, allowing the user to steer by turning the handlebars. The virtual environment is created using STISIM Drive3 software. Visuals are rendered on three 43-inch monitors for a total resolution of 5760p x 1080p and a 135 degrees field of view. Data is collected at each simulation frame, with the simulation running at approximately 30 frames per second. Ambient sounds from inside the simulation were played through the built-in speakers of the center monitor.

Scenario was built in STISIM 3, ride was 2.766 km in the ride zone with the speed limit 50km/h for cars. The weather conditions were normal with the day light.

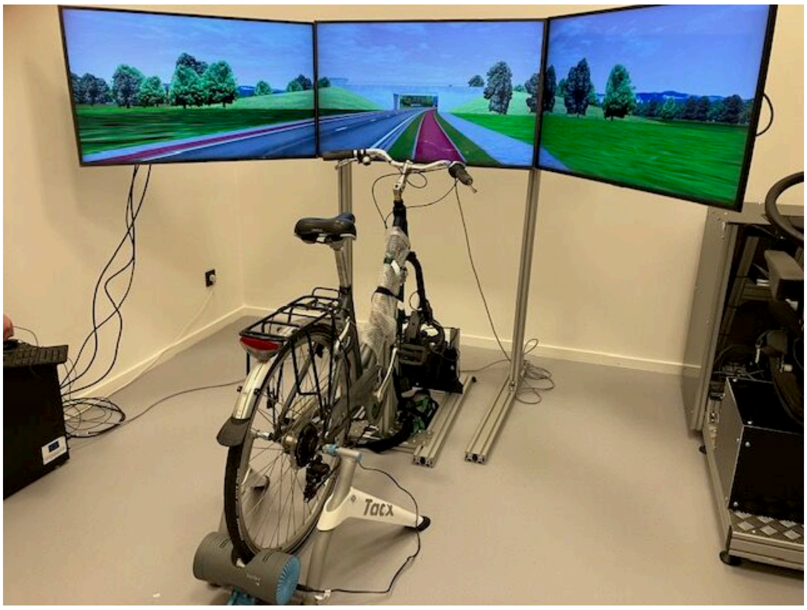

FIGURE 12 Bicycle simulator at UHasselt

The programmers wrote the scenario for testing participants with some hazards, which teenage can face in real traffic conditions. Simulation, reflects typical Belgian road surface, where red line is a separated cycle path "a" (Figure 13), grey road is a road for cars "b" (Figure 13). In the experiment are included different types of distractors, as flashing traffic light, unexpected car, the blocked view, the way-crossing pedestrian, and traffic signs. The screen of cyclist reflects speed and distance (green numbers on the Figure 13).

FIGURE 13 Simulation

In total the duration of video simulation is 05.19 min, and it includes following variables:

- GivePriorityPedestrian_1 and GivePriorityPedestrian_2. It means that pedestrian crossing the road with zebra (Figure 14, a);
- FullStopAtSign_1 and FullStopAtSign_1. Here children should stop and see if there a car approaching (Figure 14, b);
- GivePriority_1 and GivePriority_2. The hazard is hidden right after this sign. The car appears immediately; thus, child must give priority to it (Figure 15, a);
- StopOrange_1 and StopOrange_2. Changing yellow to red light indicates, that participant has to stop and wait for green signal (Figure 15, b);
- CrashVehicle_1 and CrashVehicle_2. This type of bug is hidden, because the car is parking behind the building and when person approaches it, the vehicle appears momently, and when the speed is too high or the attention is distracted, happens crash (Figure 16, a);
- CrashPedestrian_1 and CrashPedestrian_2. Some pedestrians are approaching to cycle line without zebra Figure 16, b).

Numbers after variables mean that the same type of hazard was 2 times but at different time. For instance, children should give priority to car (after the sign) two times: 1.26 min and 03.17 min. For analysis the answers of yes were changed to "1" and answers of no to "0" respectively. As example: participant stopped full at the intersection with changing yellow light (StopOrange_1 or StopOrange_2), then in analysis it was counted as "1".

a b

FIGURE 14 Variables: give priority to pedestrian and sign stop

a b

FIGURE 15 Variables: give priority sign and traffic light

a b

FIGURE 16 Variables: events: car and pedestrian

The hazards are two types: open and hidden. Open bugs are giving priority to cars and people, full stop at signs and changing traffic light (fig. 14, fig. 15). Hidden hazards are car, which is moving from the right sight behind the building that obscures the view of vehicle for cyclist, and pedestrian who is crossing the road without zebra (fig. 15, fig 16).

In the simulation were also recorded:

- Average speed normal;
- Average speed with no events: without including open and closed hazards (Fig. 14 – 16);
- SDLP (Standard Deviation of the Lateral Position) normal;
- SDLP no events.

3.2 Questionnaire

Participants had to do 2 questionnaires: pre and post. Before the experiment they answered following questions:

- How often were you involved in a traffic accident involving a bicycle in the past 3 years?
- How old are you?
- What is your gender?

After the simulation adolescents have filled in the realism and sickness questionnaire (Zeuwts et al 2023). The main aim was to figure out is objects of simulated environment were seemed to be real enough, and whether participants felt unwell while experiment.

The realism questions were divided into 3 types:

- Objects themselves (cars, pedestrians, buildings, plants, streets, cycle path, traffic lights). For instance: how realistic cars were reflected?
- Movement (cars, pedestrians, traffic). As an example of this question: how realistic did you find movement of pedestrians?
- Realism of whole simulation.

The answers were in the Likert scale, where 1 = not realistic at all, 2 not realistic, 3 neutral, 4 realistic, 5 = very realistic.

The questions about sickness were included some symptoms as: general discomfort, fatigue, headache, tired eyes, difficulty concentrating, increased salivary secretion, sweat, nausea, a “full head”, dizzy (eyes open), dizzy (eyes closed), dizziness in general, pain in the stomach, burping, general feeling of illness. The answers were according to Likert scale, where 0 = no symptoms, 1 = mild, 2 = moderate, 3 = severe, 4 = very severe symptoms.

The last part of post questionnaire was self-opinion about reactions for pedestrians, which were crossing the road at zebra or suddenly crossing without zebra; for different type of intersections (with priority from the right, with stop signs, with traffic lights); for suddenly appearing cars. The answers were ranged well by the Likert scale, where 1 = excellent, 2 = very good, 3 = good, 4 = satisfactory, 5 = poor. In the end participants were asked to estimate the general reaction to traffic situations. The answers were ranged in the same way: from 1 to 5.

4 PROCEDURE

For the experiment participants were recruited via social media (LinkedIn and other), via direct mails to schools and via UHasselt personnel. After confirmation of participation, adolescents and their parents were asked to come to university. Parents filled in informed consent, then children wrote in pre-questionnaire, which was aimed to figure out background information. It was received approval from ethic committee for experiment conducting.

Before setting the experiment, children were instructed, and it was made a small cycling exercise (ca. 1 min). Then the experiment started, test ride took around 15 min. After the simulation, children were asked to fill in post-questionnaire, which were related with sickness and realism. The whole duration consisted of 30 min. Afterwards they received a small gadget e.g., reflective bracelet.

The data of test ride was gained and saved in the comma-separated values file (.cvs). The information from pre- and post-questionnaires were reflected in SPSS format (.sav).

For analyzation the data of simulated ride was converted into excel file and highlighted the variables (see 3.1). As each data set was related to each participant, for convenience and to avoid mistakes, it was united to one file and transferred to SPSS program with (.sav) extension.

For analysis it was used IBM SPSS Statistics, version 28.0.1.1 (14) and descriptive algorithms as T-test, Histogram, Chi-square, and Spearman Correlation. Particular importance was given to 2-tailed p (T-test), Sigma (Sig.), Asymptotic Significance 2-sided (Chi-Test). The values of 2-tailed p, Sig., and Asymptotic Significance 2-seded were compared with p-Value, which is 0.05. Thus, confidence interval was chosen as 95 %. If values were less than p-Value (0.05), then it assumed that there is a significant correlation. On the contrary, if variables showed values more than 0.05, it supposed no correlation. For the Spearman coefficient it assumed significant correlation, if its value tended to 1 or to -1.

Each school grade student was encoded in the data base and had unique ID, which is a serial number since the beginning of experiment. The experiment was lasted from 3 April to 14 April 2023, during the Easter vacation in Belgium, so that children were free from school.

It has to be mentioned that in data were found outliers, which is ID 21 and ID 22. Probably these participants lost internet connection during the simulated environment test (see chapter Limitations). In total after excluding 2 children, it was used data from 49 participants.

The speed initially was encoded, thus for receiving speed in km/h, the original data was divided by 3. For further analysis were chosen SDLP with 0 event, which means Standard Deviation of the Lateral Position by normal ride without hazards, and speed in km/h without any events (thus, as well by normal ride without any events). SDLP and speed (without any events) were checked on outliers. Speed did not contain any unusual values, however SDLP by ID 36 showed and outlier. Specifically, Z-score of SDLP 0 events by ID 36 while algorithm "descriptive" in SPSS was more than 3. The unusual value was changed into normal by using the formula. Thus, the 2.38 m was changed to 1.40 m manually: Mean of SDLP 0 Event + 3*Standard Deviation of SDLP 0 Event.

Some values of SDLP and SDLP 0 Event contained NaN symbols, which meant that value is not available. Where it was (ID 38, ID 42, and ID 43), the value of NaN was changed to 0. It has to be mentioned that

SDLP with 0 events is calculated by ignoring the speed, while SDLP normal counts 75 m before and 30 m after an event.

Traffic accidents in 3 years was decoded as well for further analysis. If participant had an accident or accidents in past 3 years. It was decoded in “yes”, if no any traffic cases related with bicycle, then value was “no”.

Each variable: full stop at sign, stop orange, and crash vehicle checked 2 times. Thus, to figure out correlation general correlation, the formula was applied: (full stop at sign 1 + full stop at sign 2)/2; (stop orange 1 + stop orange 2)/2; (crash vehicle 1 + crash vehicle 2)/2. For analysis it was used Crash Pedestrian 1, because it was no participants, who had accidents with 2^{nd} pedestrian.

In the data set was provided the distances: distance between stopped participant and orange light (in meters), and distance between stopped participant and sign full stop (in meters). It can be noticed that each event was checked 2 times (per 1 hazard 2 events). Thus, average meaning of these variables was found: 1. Stopped at Orange Average and Stopped at Full Stop Sign Average. To figure out the average meanings, formula was applied: (distance Stopped at Orange 1 + distance Stopped at Orange 2)/2 and (distance Stopped at Full Stop Sign 1 + distance Stopped at Full Stop Sign 2)/2. It was assumed, that stopped participant is participant with speed below 1 km/h.

Descriptive analysis showed that Average distance on Orange stopping contained outliers with ID 8 and ID 16, thus these meanings were replaced with the formula: Mean of distance at orange stopping + 3*Standard Deviation (Z-values were 3.59 and 3.88 respectively). Descriptive analysis of average distance at Full Stop Sign didn’t show any outliers.

Giving priority at the intersection with a car at the right side and giving priority to pedestrians at a zebra crossing were excluded from analysis because data was encoded incorrectly. It has to be mentioned that giving priority to car contained 2 events, and giving priority to pedestrian as well for 2 times. Thus, 4 variables were excluded (Give Priority to car 1, Give Priority to car 2, Give Priority to pedestrian 1, and Give Priority to pedestrian 2).

For post questionnaire it was as well taken 49 participants, thus ID 21 and ID 22 were excluded, because their data in experiment with simulation was encoded incorrectly due to technical issues. The simulated test and questionnaire were in Dutch, thus all the data was saved as well in Dutch.

5 DESCRIPTIVE ANALYSIS

5.1 Experiment

As was mentioned in Methodology part, the variables for analysis are full stop at "STOP" sign, stop at traffic light with changing orange, crashes into cars and into pedestrians. However, there are some variables, which as well were used in conjunction with main data. It was checked:

- Gender
- Age
- Average speed without events
- SDLP
- Crashes in past 3 years
- Average number of stopping at "STOP" sign
- Average number of stopping at orange light
- Average number of vehicle crashes in simulation
- Number of crashes into pedestrians in simulation
- Stopping distance at "STOP" sign
- Stopping distance at traffic light

In total, data from 49 participants were taken for further analysis. 23 boys and 26 girls took part of the experiment. Average age of children is 12.8 years old, which can be seen on the Fig. 17.

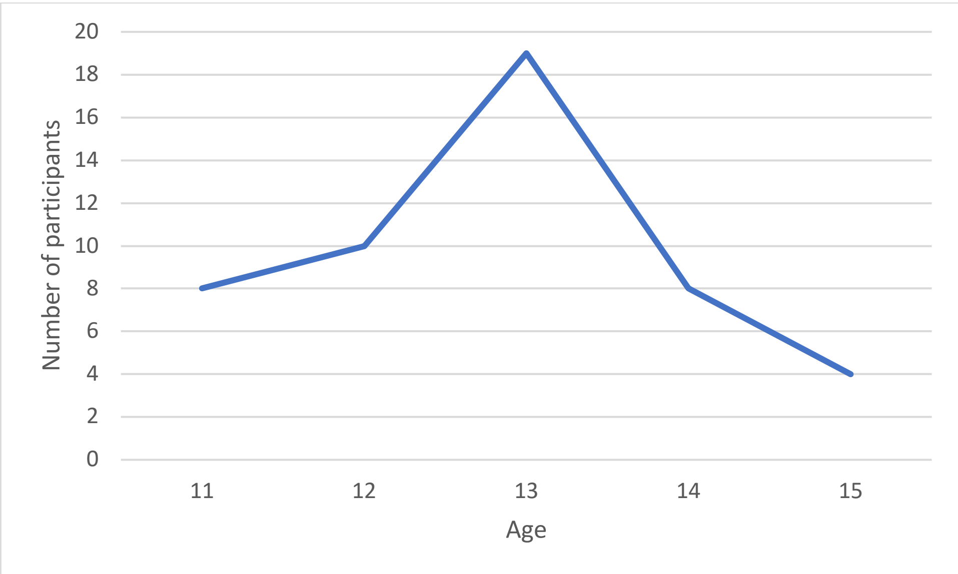

FIGURE 17 Age distribution (own elaboration)

Fig. 18 shows the distribution between age and gender of participant, where the Y axis reflects the number of participants in each age group, the X axis shows groups of age (from 11 to 15. In total 23 boys and 26 girls were taken part in the experiment.

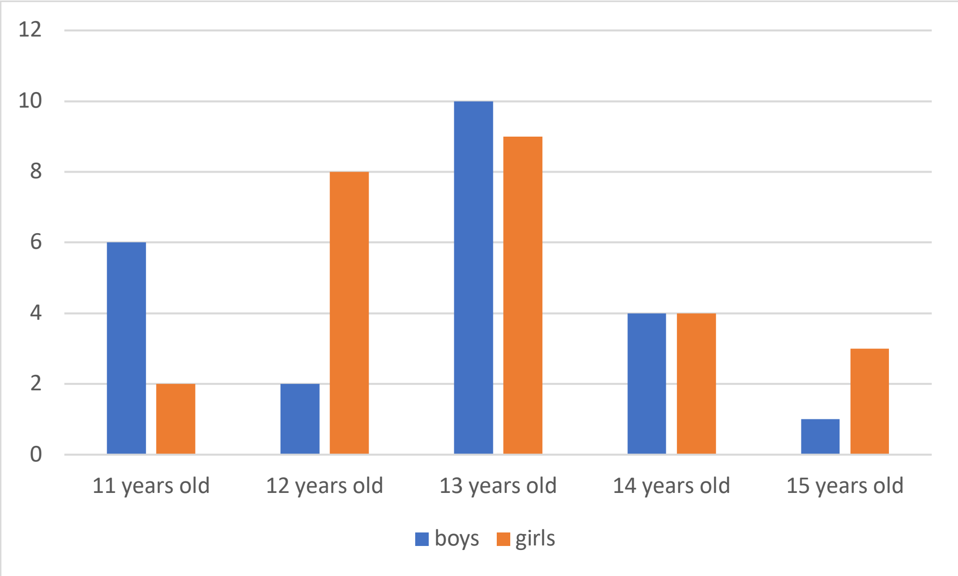

FIGURE 18 Distribution between age and gender (own elaboration)

Average age of girls is 12.92 years old ± 1.13 years old, and average age of boys is 12.65 years old ± 1.19 years old. Average speed without any events was 11.78 (±1.88) km/h, distribution between boys and girls are: 11.73 km/h (± 1.90 km/h) and 11.82 km/h (± 1.89 km/h) respectively, which shows figure below (Fig. 19). The speed ranged from minimum 8.85 km/h to maximum 16.68 km/h. Thus, girls were faster than boys, while cycling.

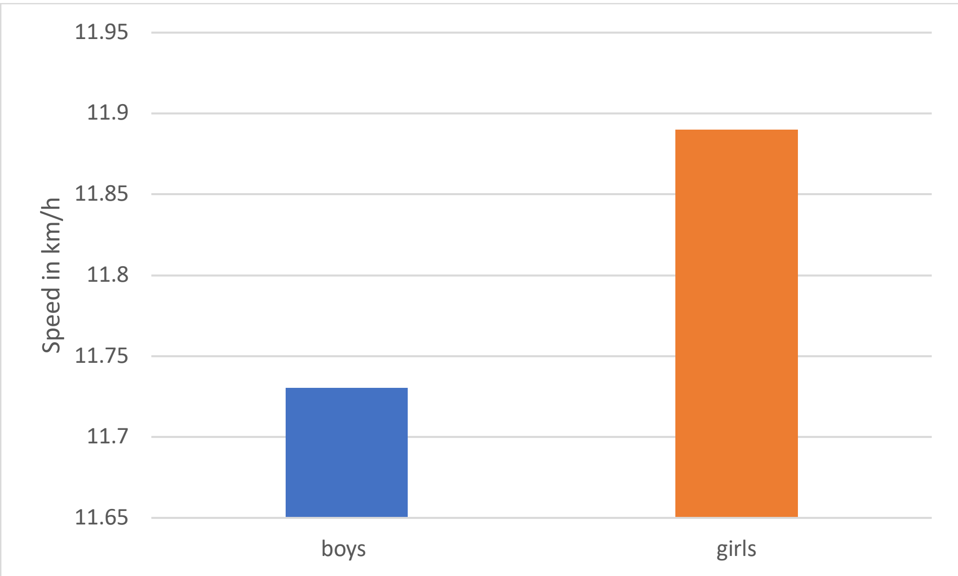

FIGURE 19 Distribution between speed and gender (own elaboration)

SDLP showed the average deviation from the handle axis. The minimum was 0.05 m, and maximum 1.40 m (±0.24 m). In average participants swerved on 0.29 m.

In past 3 years 5 people (1 girl and 4 boys) were involved in the traffic accidents by bicycle, the rest 44 answered negatively. It can be noticed that 1 boy was involved 4 times in the accidents within 3 years, while other people got into crashes just 1 time.

In general participants stopped at “STOP” sign in 80% cases. Girls stopped in average in ¾ cases, while boys did make a stop in 82% times. However, on the changing yellow light, children were more careful, and stopped in 96% situations, but it’s interesting that stopping distance at traffic light was less rather than stopping distance at “STOP” sign (Fig. 20).

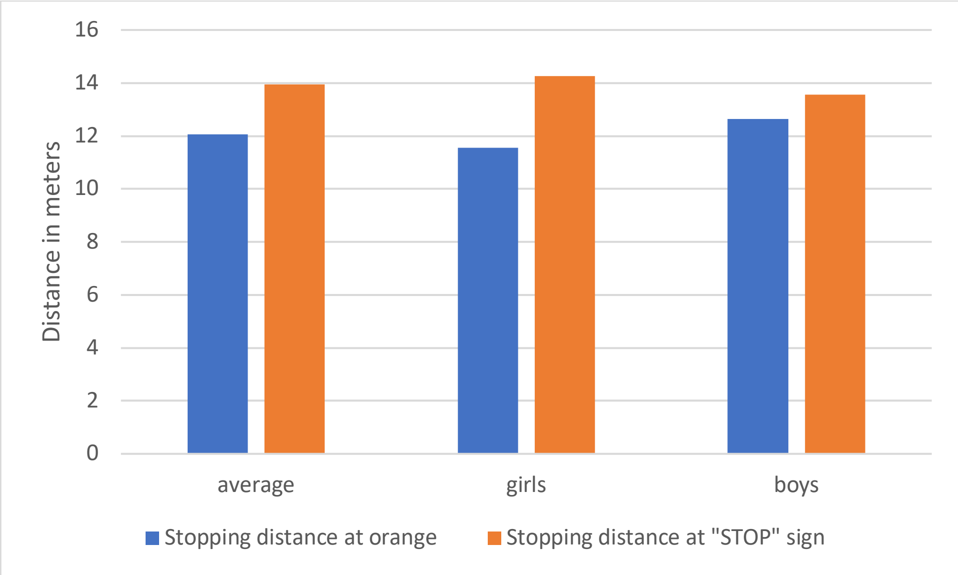

FIGURE 20 Descriptive analysis of stopping distance (own elaboration)

From the figure below (Fig.21), it might be clearly seen, that participants were involved in the vehicle crashes in the simulation more often rather than into pedestrian crashes. Girls were facing accidents with vehicles more likely than boys. In compare, almost 45 % girls, and 30 % of boys bumped into cars in experiment. However, crashes into pedestrians were on the same stage if we compare boys and girls. Only 1 girl and 1 boy were faced incidents with pedestrians.

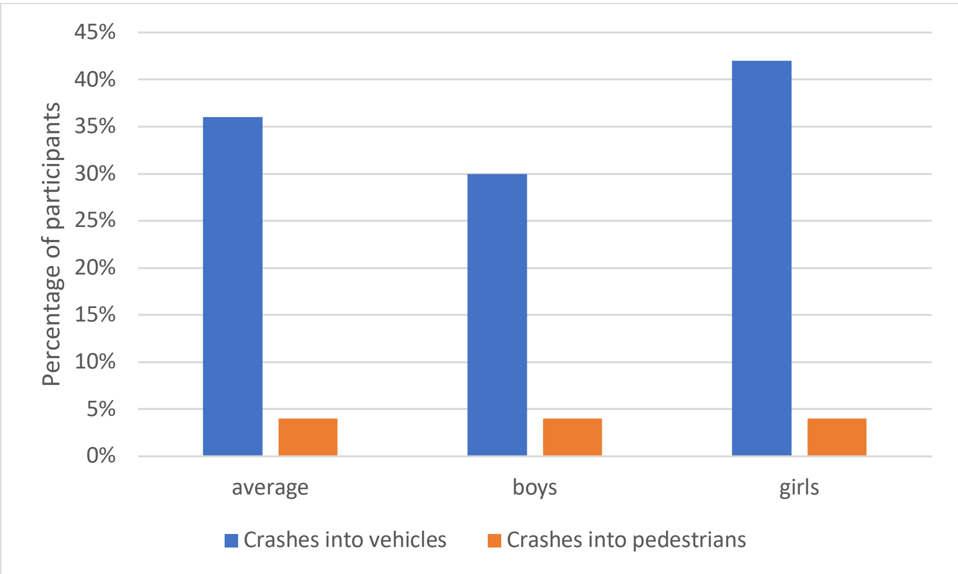

FIGURE 21 Descriptive analysis of crashes into vehicles and pedestrians (own elaboration)

The highest speed was by 13- and 14-years old participants, where 13 years old group was cycling with the average speed of 12.12 km/h, and 14 years old with 12.03 km/h. The smallest speed was by 11 years old children. In general, it can be seen an increasing trend (Fig.22).

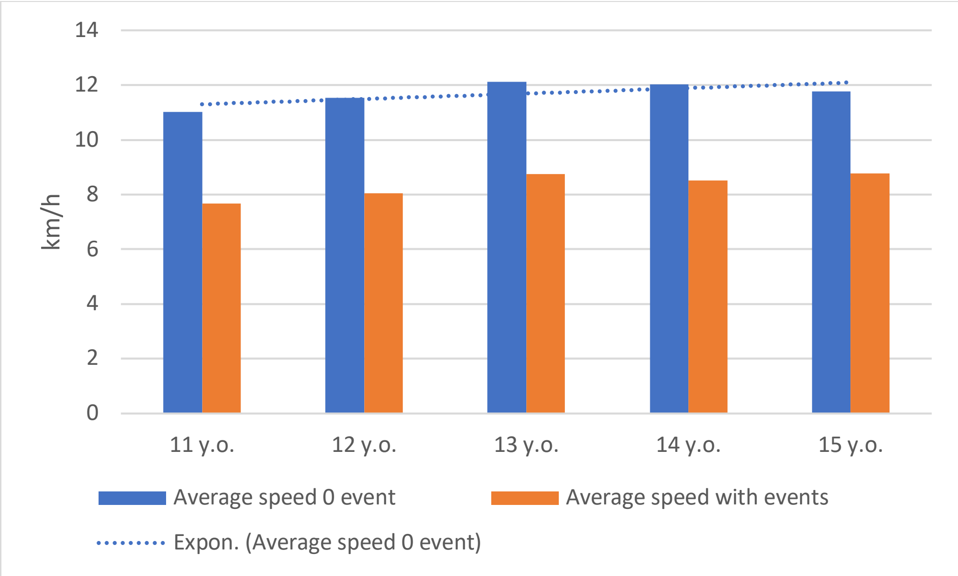

FIGURE 22 Descriptive analysis of average speed with events and without events considering age (own elaboration)

The real speed, which counted events in simulation was in 2 times smaller than average speed without events. It happened due to including all events, which took place in the simulation, as traffic lights and signs, crashes into pedestrians and vehicles.

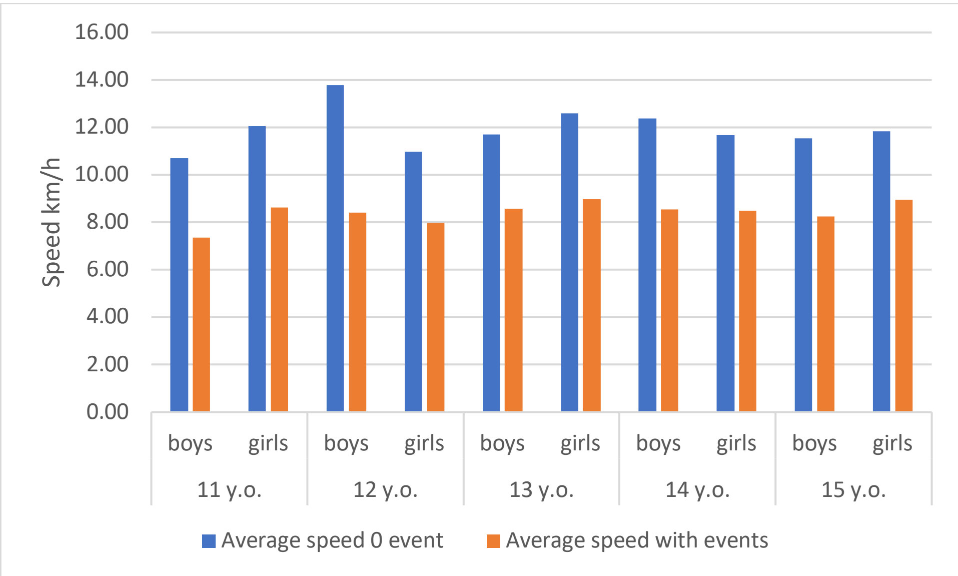

FIGURE 23 Descriptive analysis of average speed with events and without events considering age and gender (own elaboration)

On the Fig.23 it can be seen that the highest speed excluding any events had 12 years old boys. The line of speed without any events is waving and doesn't reflect any correlation between age and gender. The average speed with events in 2 times less than speed without events. However, the waving reflects the same situation as line without any events. Thus, no correlation between age and gender can be found as well for the variable average speed with events.

The average stopping distance was 12.06 m before orange light, and 13.94 m before "STOP" sign. Minimum distance was 0 and maximum distance 33.4 m before orange. By the "STOP" sign children stopped a bit closer, rather than at traffic light, the maximal distance was 27.07 m., and minimum as well 0.

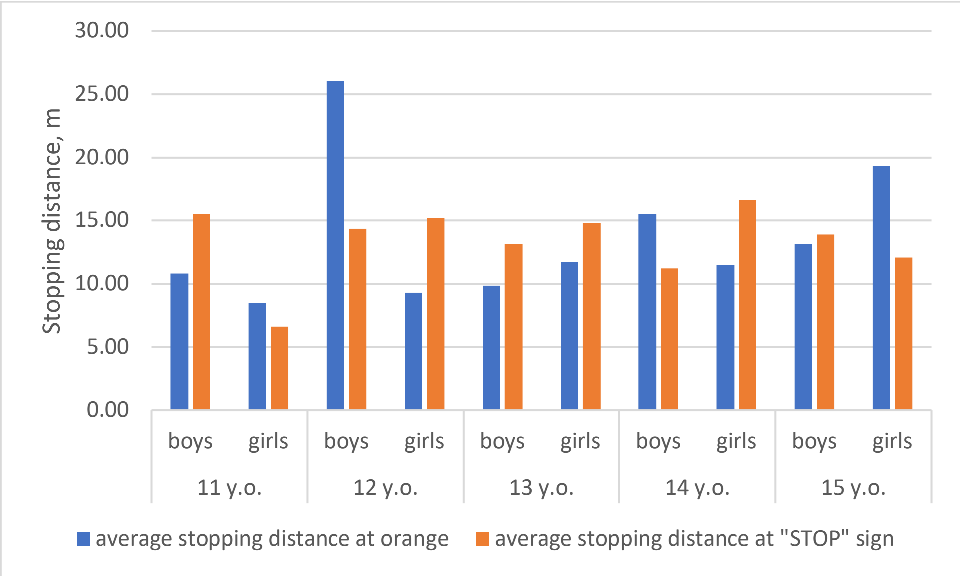

FIGURE 24 Descriptive analysis of average stopping distance on traffic light and "STOP" sign, considering age and gender (own elaboration)

On the Fig. 24 it is clearly seen that the closest stopping distance, which is slightly more than 5 m., was by 11 years girls, who made a stop before "STOP" sign. However, 12 years old boys stopped in around 26 m. before orange light, while girls did it closer, and stopped below 15 m. In general, stopping distance at "STOP" sign is waving from 5 to 15 m by both genders. From 12 years old until 15 years old, children behave similarly at "STOP" sign, while deceleration. The slowdown before orange light has chaotic picture, hence it can't be made a clear view and figure out the trend.

5.2 Questionnaire

5.2.1 Realism

The post-questionnaire was aimed to figure out any correlation between age, gender, sickness, realism and reaction. The first block of questions was about realism. Children were asked whether they found objects in simulation realistic.

Among 11 years old boys the most realistic were streets, cycle paths and footpaths (around 4.50 out of 5). 11 years girls found traffic signs, lights and streets, cycle paths and footpaths as most realistic (4 out of 5). Boys estimated movements of cars as the least realistic (2.83 out of 5), while girls found movement of pedestrians as not realistic (2.50 out of 5). General experience 11 years girls and 11 years boys estimated as 3.50 and 3.83 out of 5 respectively.

Boys from the age group of 12 years old ranged traffic signs and traffic lights as most realistic thing in simulation (5 out of 5). They also were positive about their general cycling experience on the simulator. However, 12 years old girls weren't so positive. Girls answered that they estimated their experience as 2.88 (out of 5). Some things as traffic signs and traffic lights, movement of cars, traffic in area, streets, cycle paths and footpaths were ranged by 12 years old boys from neutral to very realistic, while girls put points, which ranged from not realistic to neutral. Hence, 12 years old girls valued traffic in area as not realistic and traffic signs and traffic lights as neutral. Movements of pedestrians were ranged from 1 to 2 by boys and girls from the age group 12 years old respectively.

Although the 12 years children were very strict with the points, 13 years old group had more positive evaluation. All answers are ranged from neutral to realistic. The general cycling experience on the simulator was ranged 3.70 (out of 5) by boys and 4.11 (out of 5) by girls. The most realistic things among girls' opinion were traffic signs and traffic lights, streets, cycle paths, footpaths and cars. Boys were very enthusiastic about traffic signs and traffic lights and streets, cycle paths, footpaths aa well. The less realistic stuff was movements of pedestrians by both: girls and boys.

In the age group of 14 years old boys were very optimistic with the cycling experience in simulation, they ranged it as realistic (4.50 out of 5). However, girls weren't so positive and reported that their cycling experience was neutral (3.25 out of 5). Although plants and houses were ranged by girls as realistic, and by boys as neutral, the opinion about points on traffic signs, traffic lights, streets, cycle paths, footpaths were similar (4.25 out of 5). Movement of pedestrians was estimated as not realistic by girls and neutral by boys, which is the least realistic thing in the age group of 14 years old.

In the age group of 15 years old boys and girls weren't very optimistic about the general realism of simulation. They estimated it as neutral. The most realistic thing among boys was traffic signs and traffic lights by boys. Opposite, girls found 3 realistic things, which were traffic signs and traffic lights, streets, cycle paths, footpaths and plants with houses. Movements of cars and pedestrians were ranged by girls as neutral. However, boys estimated movements of pedestrians as not realistic at all and movements of cars as not realistic.

5.2.2 Sickness

In the 11 years old age group boys were most likely not to have any symptoms, or have just mild manifestation. The most common symptoms by 11 years girls were dizzy with opened eyes, nausea, sweating and headache (1.50 out of 5). The less common symptoms by boys were general feeling of illness, general dizziness, and headache (0.16 out of 5). Contrary, girls estimated all symptoms with the higher points than boys, and sickness which led to less discomfort, were increased salvation and eyes strain (0.5 out of 5). In general, 11 years old group rated symptoms of general discomfort from 0.16 to 0.5 by boys and girls respectively.

In the 12 years old age group on the contrary, girls had less symptoms than boys. Sweating was reported as most common symptom within boys (1 out of 5). Girls claimed they had blurred vision, a "full" head, sweating and difficulty concentrating on the insignificant level. The most common symptom among girls was eyes strain (0.5 out of 5). Boys didn't feel general discomfort, while girls reported, they had mild symptoms of it (0.25).

13 years old boys showed greater susceptibility to symptoms rather than girls. The most severe symptoms among boys were general feeling of illness (0.60 out of 5), difficulty concentrating (0.80 out of 5), and general discomfort (0.70 out of 5). Having to burp was the less common symptom among boys (0.10). 13 years old girls had eyes strain (0.44 out of 5) as most severe symptom. The rest as blurred vision, a "full" head, nausea, sweating, increased salivation, difficulty concentrating, and fatigue were insufficient. Girls didn't report about having to burp, upset stomach or any dizzy with closed eyes. These symptoms had just boys. In general girls complained that they had small discomfort (0.22), which is less than 0.70 if compared to boys.

In the 14 years old group boys had just 2 symptoms, which are sweating (0.75 out of 5) and a "full" head (0.25 out of 5). Girls didn't feel such symptoms as having to burp, upset stomach, general dizziness, and dizzy while open and closed eyes. The most severe symptoms among girls were difficulty concentrating (0.75 out of 5) and general discomfort (0.75 out of 5). The rest symptoms were equally spread among girls with mild manifestation.

The last age group, which is 15 years old represented 3 girls and 1 boy. Boy reported he had eyes strain (1 out of 5), while girls had just headache (0.3 out of 5) and general feeling of discomfort (0.3 out of 5).

5.2.3 Reaction

The last part of questionnaire was aimed to figure out the meaning about self-reaction of children. It was estimated reaction in general, reaction of suddenly departing cars, intersections with traffic lights, intersections with stop signs, intersections with priority from the right, sudden crossing pedestrians and pedestrians at zebra. All answers were according to Likert scale, as was mentioned in the Methodology part, where 1 considered as excellent, 2 as very good, 3 as good, 4 as satisfactory, and 5 as poor.

Among 11 years old children the best reaction was on intersections with traffic lights (1 out of 5), which means they tend to think that they reacted excellent on this event. However, 11 years old girls were stricter and estimated own reaction as between very good and good (1.50 out of 5). Mostly girls reported they were good at all events, but suddenly departed cars and pedestrian suddenly crossing the road were more challenging. They claimed for cars 2.50 and 2 for pedestrians (out of 5). Although 11 years old boys reported that they reacted very good on all hazards, the reaction for suddenly departing car was worse than by girls. They put around 3 points out of 5. In general, 11 years old girls estimated own reaction in 1.50 points, while boys claimed they reacted on 2 points (out of 5).

The 12 years old age group reported that the worst reaction they had on suddenly departing cars, 3.13 by girls and 3.00 by boys (out of 5). There is as well tendency, that boys tend to think they had a better reaction than girls. However, children equally estimated intersections with priority from the right with 2.00 points, which mean "very good". The best reaction according to the boy's opinion was on 3 events: intersection with traffic lights, intersections with stop signs and pedestrian crossing zebra. 12 years old boys claimed, they did it excellent. Girls, on the contrary mostly estimated themselves as very good to good (2 or 3 out of 5), and never claimed that their reaction was excellent. In general girls thought their reaction on the events in simulation was "good", while boys reported about "excellent reaction."

Girls from 13 years old age group ranged their reaction from good to satisfactory (1.50 – 4.00 out of 5). They claimed that their reaction on suddenly departing cars was near satisfactory (3.67 out of 5), while boys reported about good reaction (3.10 out of 5). Although had tendency to estimate themselves better than girls, the answers of boys were ranged from 1.40 to 3.10, which means, they didn't think that their reaction was excellent. Mostly 13 years old boys were of the opinion, that they reacted good and satisfactory. 13 years old boys estimated their reaction on intersections with traffic lights with 1.40 points (out of 5), while girls' reaction was 2.22 (out of 5). In general, 13 years old children claimed that their reaction on simulated events was from 1.90 (out of 5) to 2.33 by boys and girls respectively.

14 years old children didn't rate their reaction as excellent as well. Their answers on events were ranged from 1.50 to 3. The event, on which they had bad reaction was suddenly departing cars. Here answer among boys and girls were almost the same: 1.25 and 1.75 respectively. Girls reported that their reaction on pedestrians at zebra crossing was 2.25, while boys was more optimistic, and rated this event as 1.25 (out of 5). The best reaction boys awarded to intersections with traffic lights (1.25 out of 5). Girls were as well positive about this event, and ranged it as 1.50 (out of 5), which means good reaction. The general reaction on events in simulation boys estimated between good and very good, while girls' answers were "very good".

The last age group which is 15 years old represented 1 boy and 3 girls. The boy claimed that reaction on intersection with stop sign was good (3 out of 5). 15 years old girls reported that the weakest reaction they had on suddenly departing cars: almost 4 out of 5. However, the boy's meaning was quite positive about this event, and he tended to think, his reaction was excellent. Girls thought they had from very good reaction to good on pedestrians at zebra, while boy claimed his reaction was "excellent". In general boy shared that his reaction on simulated events was very good, while girls reflected their reaction from very good to good.

6 STATISTICAL ANALYSIS

6.1 Experiment

The two-tailed T-test was taken to figure out any correlation between gender and speed. The 0 hypothesis has assumed that girls and boys ride the bicycle with the same speed. Sig.= 0.858, which is more than p-Value (0.05), thus the 0 hypothesis was taken for further analysis. Two-Sided p = 0.873, which is also more than p-Value.

For follow the correlation between age and average speed without any events, it was used Spearman correlation coefficient in SPSS, because data are multiple. The Spearman's coefficient was 0.197, which is remoted from 1 or -1. Sig. (2-tailed) was 0.176, which is more than 0.05.

It could be seen that from 49 participants, only 5 of them had traffic accident (or accidents) with bicycle: 1 girl and 4 boys. Chi – Square test shows Asymptotic Significance (2-sided), which is 0.118 and slightly more than 0.05. As 2 cells have expected count less than 5, Fisher's Exact Test (Exact Sig. 2-sided), which is 0.173 was used. It assumes, that 0 Hypothesis, which is there are no difference between gender and correlation between accidents in the past 3 years was taken for further analysis.

To figure out correlation between age and accidents in past 3 years it was used as well Chi – Square test. Only one 11 years old person and one 13 years old participant, and 3 people from 14 years old group had traffic accidents. As 6 cells have expected count less than 5 (60 %), it was taken Likelihood ratio for further analysis. The Likelihood ratio is 0.097, which is slightly more than 0.05, which means that there is weak correlation between age and accidents in past 3 years.

It was checked the correlation between gender and stopping at orange light. Sig.=0.009, thus the 0 Hypothesis that data are equal is rejected, and 1 Hypothesis is assumed. Two-Sided p=0.185, which is slightly more than 0.05.

The connection between age and stopping at orange light was checked within Spearman correlation. Correlation coefficient was 0.062, which is remoted from -1 or 1. Sig. 2-tailed was 0.671.

At the intersection with the Full stop sign, girls are stopped in 0.78 cases (±0.32), whereas boys in 0.82 (±0.28). Sig. = 0.423, which is more than p-Value, thus 0 Hypothesis is assumed, that there are no differences in data. Two-sided p=0.669, which is also more than 0.05.

The Bivariate test showed that Spearman's Correlation coefficient is -0.293 and sig. (2-tailed) is 0.041 for the age and full stopped at sign.

Girls had crashes with vehicles in 0.42 (±0.39) and boys in 0.30 (±0.32) cases. Sig.=0.507, thus the 0 Hypothesis is assumed, Two-sided p=0.130, which is different than 0.05.

Relationship between age and vehicle crashes in the simulated environment was tested with Spearman's coefficient, which was 0.068, sig. was 0.645, thus 0 Hypothesis is assumed.

Only 2 participants had crash with pedestrian, 1 boy and 1 girl. Thus, the 0 Hypothesis was assumed, because sig.=0.863 and 2-sided p-Value=0.931. The relation between age and pedestrian crash is week, where Spearman's coefficient = -0.030, and Sig.=0.836.

Spearman's correlation coefficient between average speed without any events and accidents in past 3 years is -0.040 and Sig. (2-tailed) =0.785. In other case, where correlation between accidents in past 3 years and stopped for orange were checked, Spearman's = 0.069 and Sig. (2-tailed) = 0.635.

Correlation between Full Stop at Sign and accidents in past 3 years was checked, it appears, that Spearman's = 0.088 and Sig. (2-tailed) = 0.549. 3 types of correlation by Spearman's coefficient were checked as well: between accidents in past 3 years and crashes into pedestrian in simulation (Spearman's = -0.069, Sig. (2-tailed) = 0.635), accidents and SDLP without any events (Spearman's = 0.039, Sig. (2-tailed) = 0.796), accidents and vehicle involvement crashes in average in simulation (Spearman's = 0.239, Sig. (2-tailed) = 0.098).

T-test showed that average stopping distance on orange light was 11.56 m (±6.18) by girls and 12.64 m (±6.42) by boys. Levene's Test for Equality of Variances showed Sig. = 0.670, thus 0 Hypothesis is, which is equal variances are assumed, was taken for analysis. Two-Sided p = 0.552, which shows no correlation between gender and average distance.

It was checked correlation between age and stopping distance at orange light. Spearman's coefficient = 0.290, Sig. (2-tailed)= 0.043.

T-test showed that girls stopped at Full Stop Sign in 14.27 m (±7.13), while boys stopped in 13.56 m (±6.83) before sign. Leven's Test for Equality showed Sig.=0.975, where 0 Hypothesis is assumed (data are equal). Two-sided p = 0.724, thus 0 Hypothesis, which there are no correlation is assumed.

Spearman's coefficient which is -0.031 and Sig. (2-tailed)=0.831 were calculated to check correlation between age and average stopping distance before Full Stop Sign.

6.2 Questionnaire

6.2.1 Realism

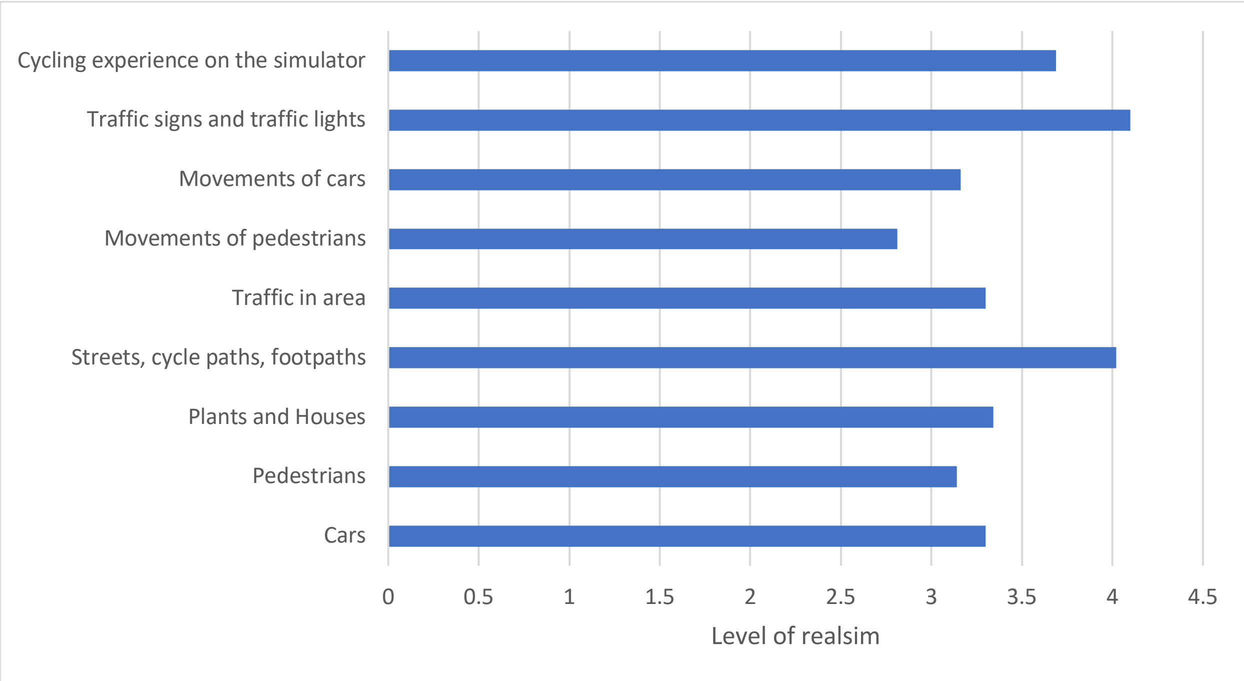

FIGURE 25 Distribution between factors and realism level (own elaboration)

49 participants ranged the realism of car's representation from 2 to 5, where 2 is not realistic and 5 is very realistic. In average estimated the realism of cars neutral (Mean 3.3, Std. Deviation 0.96). Description of pedestrians were ranged from 1 to 5, where average is 3.14 (±0.95). Buildings and houses were found as neutral (3.34±0.9), which is the same as movement of cars (3.16±1.007), traffic in the area (3.30±0.82). However, streets, cycle paths, footpaths (4.02±0.82) and traffic signs, traffic lights (4.10±0.96) children found realistic. The movement of pedestrians in simulation children rated as not realistic (2.81±1.18). In general, participants estimated the realism of simulation in experiment as neutral (3.69±0.98) (Fig. 19).

In general girls estimated experiment neutral (3.5±1.06), and boys ranged simulation a bit higher, but also neutral (3.9±0.84). Levene's Test showed Sig.=0.232, thus 0 hypothesis was assumed and Two sided p in Significance test showed 0.144 points.

Chi-square test showed that in the age group of 11, 1 person found simulation not realistic, 2 persons estimated it as neutral, 3 people highlighted that experiment was realistic. 2 last person in this age group described simulation in general very realistic.

In the group of 12 years old children, most participants found simulation neutral and realistic. Other few participants are equally distributed between very unrealistic, unrealistic and very realistic. 13 years old children noted that experiment realism was ranged from neutral to very realistic. In the 14 years old group the result distributed as well between neutral and very realistic. However, 1 person in this age group voted that simulation was very unrealistic. 15 years old participants was more optimistic about simulation and voted from neutral to realistic general realism.

To figure out correlation between answers of realism and age, it was used Spearman's coefficient, which was weak 0.108, and Sig. 2-tailed=0.462, which is 8 times more than 0.05.

6.2.2 Sickness

It was checked different simulation sickness, which might appear during or after experiment, thus Sickness Questionnaire was used. The answers were ranged according to Likert Scale, from 0 (no symptoms) until 3 (severe). Nobody has chosen 4, which means very severe symptoms. Such symptoms as general discomfort, headache, difficulty concentrating, nausea, a "full head", dizzy (eyes open), dizziness in general, burping, were ranged from 0 symptoms to severe symptoms. Blurred vision or upset stomach was estimated maximum up to 1 (mild symptoms). The rest were ranged from 0 to 2 strength, which are from 0 symptoms until moderate. The most common symptoms, which participants felt, were general discomfort (Mean 0.44±0.73), tired eyes (Mean 0.40±0.60), and sweat (Mean 0.40±0.67). The most uncommon symptoms were pain in the stomach (Mean 0.06±0.24) and burping (Mean 0.08±0.44) (Fig.20).

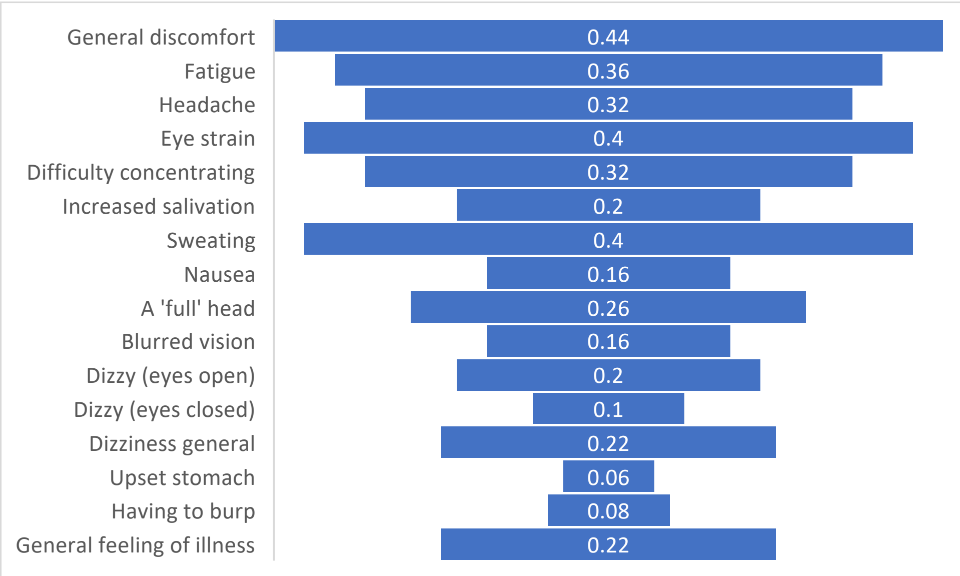

FIGURE 26 Distribution between factors and sickness level (own elaboration)

Correlation between age and symptoms were checked with the help of Spearman's coefficient, which was -0.010, and Sig. (2-tailed) was 0.943. T-test showed that girls felt general sickness in 0.15 cases (±0.36), while boys in 0.30 cases (±0.55). Levene's test showed that equal variances are not assumed (Sig.=0.025, which is less than 0.05), thus 0 Hypothesis is rejected, and 1 Hypothesis is assumed. Two-sided p=0.279, which is 4 times more than 0.05.

39 participants from 49 had no sickness during or after experiment at all, however 9 children noticed mild symptoms. It was people from 11 years old, 13 years old and 14 years old groups. Only one 13 years old person felt moderate symptoms of general sickness.

6.2.3 Reactions

Participants voted that general reaction to traffic situation was from 1 to 3, where 1 is excellent reaction, and 3 means good reaction. Intersections with traffic lights and suddenly departing cars were estimated from 1 to 5, where 5 is poor reaction. The rest events were ranged from 1 to 4 (satisfactory reaction).

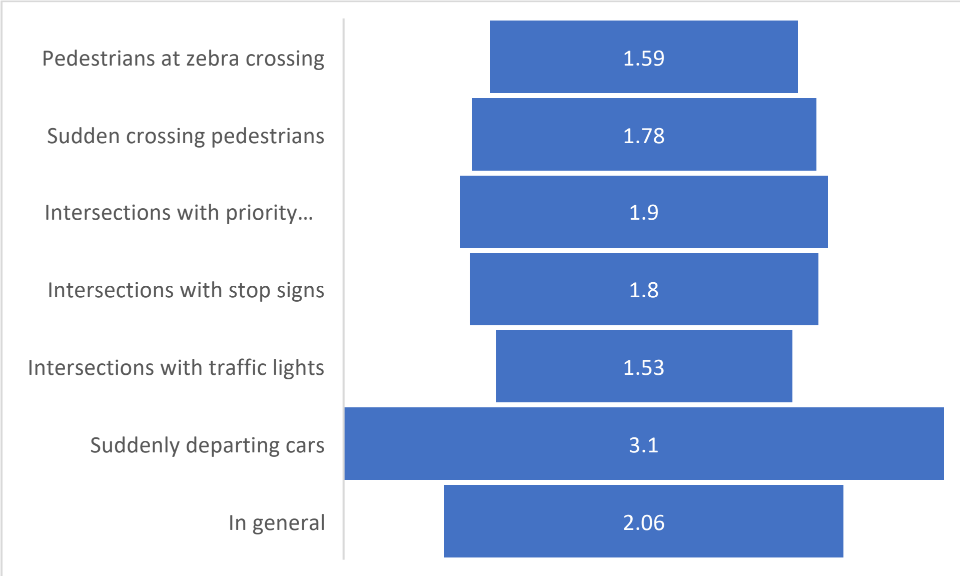

FIGURE 27 Distribution between factors and reaction level (own elaboration)

The best reactions according to self-questionnaire were reaction on pedestrians, crossing the road by zebra (Mean 1.59±0.734) and intersections with traffic lights (Mean 1.53±0.844). The most difficult event, where reaction was insufficient, was suddenly departed car (Mean 3.10±1.06). Children estimated general reaction as very good (Mean 2.06±0.55) (Fig.21).

T-test showed that girls tend to estimate their general reaction on events in simulation as very good (Mean 2.15±0.613), while boys tend to think that they had a better reaction (Mean 1.96±0.475). However, during Levene's Test equal variances are assumed, thus 0 Hypothesis was assumed (0.078 is slightly more than 0.05) and Two-sided p showed 0.218 level of significance, which as well more than 0.05.

34 participants think that they reacted on events in experiment good, most of them are from 11 years old group. 9 participants find that they reacted neutral, the most are from 13 years old group as well. Only 6 people gave opinion, that their reaction was excellent, again most of them are from 13 years old group.

Spearman's coefficient was checked between age and general reaction. Results show that Spearman's=0.104, and Sig (2-tailed) is 0.476, which is more than 0.05.

7 RESULTS

7.1 Experiment

23 boys and 26 girls took part in experiment with bicycle simulator and in post-questionnaire. Average age of boys and girls were alike (12.92 years old by girls and 12.65 years old by boys). Minimum SDLP was 0.05 m and maximum of 2.38 m. In average children rode a bicycle with 0.31 m of SDLP, which means, that deviation from the central axis of handlebar was not significant. 2 participants from 51 were excluded from further analysis, because the data was decoded incorrectly due to internet connection loosing. Variables give priority to car and pedestrian were as well excluded due to the same reason. SDLP contained outlier, so it was replaced with the formula, given in Procedure part. Average stopping distance before orange light was checked for outliers' existence, so that 2 outliers were successfully replaced.

T-tailed test showed that there are no differences between girl's and boy's average speed, hence, here is no correlation between these 2 values. Average speed without any events was 11.73 km/h (±1.90 km/h) among boys and 11.82 km/h (±1.89 km/h) among boys.

Spearman's coefficient negligible relationship between age and average speed, the value of sigma was in 3 times more than p-value, which can be interpreted, that different ages (11 – 15 years old) had alike speed during experiment.

In the simulated environment, participants were facing more incidents with cars rather than with pedestrians. Girls crashed the vehicles in the simulation more often rather than boys. Age group of 13 and 14 years old had the average speed of 12.12 km/h, while 14 years old participants preferred to ride bicycle with the average speed of 12.03 km/h. The stopping distance before "STOP" sign was closer rather than before traffic light. From 12 to 15 years old children behaved in the same way near the "STOP" sign while deceleration. The deceleration in front of the orange light has an erratic pattern, so it cannot be clearly discerned and a trend can be identified.

From 49 participants only 5 had accidents related with bicycle in past 3 years. It was 1 girl and 4 boys. Chi-square test was used to interpret any correlation between gender and accidents. As 2 cells have expected count less than 5, Fisher's exact test was used for interpretation. It showed that there is no correlation between gender and accidents in past 3 years. It was used Chi-square test as well for figure out relationship between age and accidents, as 6 cells have expected count less than 5, it was used Likelihood ratio, which was slightly more than 0.05 (Likelihood 0.097), thus no correlation is assumed.

T-tailed test between gender and stopping at orange assumed 1 Hypothesis is taken, which means, that data are unequal. However, correlation between these 2 variables, are not found. Connection between age and stopping at orange was checked through Spearman coefficient. It revealed no correlation as well.

Bivariate test gave information about age and full stop at sign. With the help of Spearman coefficient and Sig. (2-tailed), it displayed negative relationship. It means that there is a strong correlation between age and stopping at sign. Children, from the younger group are stopping more often at stop sign, rather than their old participants.

However, there was found no correlation between gender and crashes with vehicle in the experiment. The data set was equal as for girls as well for boys. The same can be said about age and vehicle crashes, no relationship between these 2 variables. It was also checked correlation between gender and pedestrian crashes, and age compared with pedestrian crashes in simulation. The analysis showed no relation.

Bivariate test gave information about average speed and accidents of participants in past 3 years (in real life). Spearman coefficient was negative, however not significant, and sig. (2-tailed) was in 15 times more than 0.05. It means, that no correlation between average speed in simulation and accidents in past 3 years was found. The same result, as no relationship, can be noted for stopped at orange and accidents in past 3 years. The Spearman coefficient in case of full stop at stop sign and accidents in real life was trivial, as well as 2-tailed sig., which was several times more than p=0.05. It indicates no correlation.

It was checked relations between crash into pedestrian in simulation and crashes in past 3 years in real life, and analysis didn't show any correlation. The same output with the SDLP and crashes in past 3 years, which means that deviation from the central handlebar position didn't depend on crashes, which participant had in real life. However, it was found weak positive correlation between crashes into vehicle in experiment and accidents in past 3 years. It means, that children, who had accidents in past 3 years had crashes into cars in experiment.

T-test reflected that although girls stopped before orange in 11 meters, and boys in 12 meters, still data set is the same: standard deviation by girls and boys, stopping at orange, was around ±6 meters in both cases. Two-sided p was significant more than p-value, hence there is no correlation. Boys and girls stopping distance almost the same, thus gender doesn't affect.

However, there is a moderate correlation between age and stopping distance. The older was participant, the closer he stopped before orange light. It means, that 11 years children stop before orange further, rather than 15 years old, who did it closer.

It was checked the relationship between stopping distance at full stop sign and gender. Although boys stopped closer than girls (13 meters and 14 meters respectively), the statistical analysis didn't appeal any correlation. The 0 Hypothesis approved, which means that data set is equal. Two -sided p is significantly more than p-value, which also notifies that there is no correlation between gender and stopping distance at stop sign. The same could be applied for age and stopping distance at sign. Spearman's coefficient is weak, and sig. (2-tailed) in 16 times more, which highlights no correlation between these 2 variables.

Making a conclusion about experiment and statistical analysis, it could be highlighted, that younger participants had more accidents in past 3 years rather than older. The data set of girls and boys by stopping at orange was different, however, in the final analysis no correlation between these 2 variables was found. However, while checking relationship between gender and full stop at stop sign, was appealed negative correlation. It means, that the younger participants stop before sign more often rather than older. It was revealed that there is positive connection between accidents in past 3 years by bike in real life and crashes into vehicle in experiment. It means that if participant had an accident in the past by bicycle, the more likely he had a crash with vehicle in simulation. The last correlation was found checking age and stopping distance at orange light. The older a participant was, the closer he stopped to the traffic light. In other cases, no correlation was approved.

7.2 Questionnaire

Post Questionnaire was held after experiment, and children were asked about realism of simulation, sickness and estimation of self-reaction on events. Participants estimated cars, pedestrians, houses, traffic of cars and general traffic as neutral. They found more realistic streets, road signs and traffic lights. Only movement of pedestrians children ranked as not realistic. In general, they were neutral about whole realistic of simulation. The data set of children were equal regarding the meaning of general realism, and nor boys', nor girls' reflection differ. In other words, there was no correlation between gender and ranking of realism. The general realism didn't correlate as well with age. As older, as younger participants had the same answers. Most of them: 15 participants and 20 participants estimated general realism of experiment as neutral and realistic respectively.

11 years old group found streets, cycle paths, traffic signs and traffic lights as realistic. The not realistic things according to boys and girls in this age group were car movements and pedestrian movements. 12 years old agreed that traffic signs, traffic lights, cycle paths were realistic. Girls tended to think that traffic signs, traffic lights and traffic in the area were neutral. 13 years old children were more positive about realism of events in simulation. The most real things, according to the girls, were road signs and traffic lights, streets, cycle paths, footpaths and cars. Boys were more enthusiastic about road signs and traffic lights, as well as streets, bicycle paths, pedestrian paths. Less realistic were the pedestrian movements by boys' and girls' opinion. 14 years boys were very enthusiastic about their cycling experience in the simulation and rated it as very realistic, while girls rated it as neutral. In the age group of 15 years old children were neutral about general realism of simulated experience. 15 years old girls claimed that traffic signs, lights and cycle paths were more realistic, rather than movement of pedestrians and cars. 15 years old boys estimated movement of pedestrian as unrealistic at all, and movements of cars as unrealistic.

Such symptoms as general discomfort, headache, difficulty concentrating, nausea, a "full" head, dizzy (eyes open), and having to burp were estimated as severe symptoms. However, the most common symptoms were general discomfort, tired eyes and sweat. The rare symptoms were upset stomach and having to burp.

Among 11 years old group, both by girls and boys, were only light symptoms of simulation sickness. In general, the children from this age group estimated their symptoms of general discomfort from 0.16 to 0.50 which means very mild symptoms, almost imperceptible. However, 12 years old boys were more susceptible to symptoms. Sweating was the most common symptom among boys and had mild influence. Eye strain was the most frequent symptom among girls with almost imperceptible manifestation. Boys felt no overall discomfort, while girls reported mild discomfort. The 13-year-old boys showed greater susceptibility to symptoms than the girls. They had small difficulties with concentration and mild general discomfort. Girls from 13 years old group noticed strain in eyes, however as well, only light symptoms. Overall, girls complained of little discomfort (0.22), which is less than 0.70 compared to boys. It means, that girls had miserable symptoms of general discomfort, while boys were closer to mild symptoms. In 14 years old group boys had only sweating and feeling of "full" head, however they were mild. Girls had mild symptoms of general feeling of discomfort. The last age group, namely 15 years, was represented by 3 girls and 1 boy. The boy had eye mild strain and the girls had only lightly seen symptoms of headache and of general discomfort.

Although data set showed that girls had less symptoms than boys (0.15±0.07 and 0.30±0.11 respectively), the T-Test showed that feeling of general sickness after or during experiment didn't relate with gender. It means that despite the data set of girls and boys had different answers, there was still no correlation between gender and feeling of sickness. Only 9 people had mild symptoms of general sickness, while 39 didn't any of them at all. It was checked relationship between age and general sickness, which children might have during simulation experiment. After statistical analysis it wasn't found any correlation. The Spearman coefficient is very weak and Sig. (2-tailed) in many times more than p-value, which proves no correlation.

The last questions of post questionnaire were aimed to figure out children' self-meaning about their reactions to events in simulation. Children found that intersections with traffic lights and plots of departing pedestrians were the most difficult. Participants estimated their reactions on these 2 events as "very bad". Although the rest answers were distributed to "bad reaction" (pedestrians at zebra, sudden crossing pedestrians, intersections with priority from the right, and intersections with the stop sign), the general reaction on events children ranked as "neutral". In general girls tended to range their reaction from very good to neutral, while boys estimated own reaction as excellent, and sometimes as very good.

Although 11-year-old boys reported that they reacted very well to all hazards, the reaction to a suddenly departing car was worse than for girls. In general, the girls reported that they were good at all the events, but the more difficult ones were the cars pulling away suddenly and pedestrians crossing the road suddenly. 12 years old group claimed that suddenly departing cars were the most difficult events with bad reaction. 13 years old girls as well tended to think that suddenly departing cars were most challenging event in simulation, because their self-reported reaction was estimated as satisfactory. Boys in this age group were more enthusiastic on suddenly departing cars and claimed that their reaction was good. In general children reported that their reaction on simulated events were from very good to good. 14 years old children's responses were ranged from excellent to good. The event to which they reacted poorly was cars suddenly driving away. Here the boys' and girls' responses were almost equal: "I did it from excellent to very good". 15 years old girls claimed that their reaction on departing cars were satisfactory, which is 4 out of 5, where 5 is poor. However, the boy's attitude towards the event was quite positive, and he tended to think that his reaction was excellent. Overall, the boy shared that his reaction to the simulated events was very good and the girls reflected their reaction from very good to good.

The most common opinion about plots of departing cars was: "I reacted normal". For the question: "How do you think you reacted to the traffic situations in general", the average answer was: "I reacted good". For the pedestrians at zebra, sudden crossing pedestrian, intersections with the right priority, and intersections with traffic lights and stop sign, children found their reaction in average as very good.

Girls estimated their reaction in general as good, while boys tended to rank their reaction as very good or excellent. However, T-test showed that the data set was almost equal, and Two-Sided p. reflected that there is no correlation between girls' and boys' opinion between estimation of their reaction on events in simulation in general. It means boys and girls had the same reaction for the events in simulation.

In average 34 people estimated their reaction as very good, and only 6 participants noticed they reacted excellent. Spearman coefficient didn't show any correlation between gender and self-reaction in general. It proves Sig. (2-tailed), which is significantly more than p-value. Thus, there is no relationship between age and reaction.

As a conclusion, it can be noticed that in post questionnaire wasn't found any correlation between age, gender, sickness, realism and reaction. Only the data set of boys and girls was unequal, while checking the influence of general sickness to gender. However, still there was no correlation between gender and general sickness during or after an experiment.

8 DISCUSSION

In this work was revealed that the older participant was, the less times he stopped at sign “STOP”, thus it proves that there is a correlation within accidents, dangerous situation, and risky behaviour. Thus, teenagers (14-15 years old) ride a bicycle in more risky way, that 11-13 years old children. To the same conclusion came Feenstra with colleagues (2010). In his study he discovered the positive connection between age and risky behaviour. The tendency to risky behaviour among age group 14-15 years old proves our result as well that the older were participants, the closer they stopped before changing orange (changing from orange to red). It correlates with the Taniguchi and colleagues (2022) study, in which they describe connection between age and risk.

Iversen and Rundmo (2004) demonstrated that drivers, who have less awareness about traffic safety or drivers, who are tend to overspeed, are more prone to have risky behaviour. Our results din’t testify the Hypothesis. It showed, that there were mild relation between crashing vehicle in experiment and in real-time within 3 years.

Taniguchi et al. (2022) revealed that cyclists in the age of 13-15 had less crashes rather than 16-19 age group. Hence, the age has positive correlation with accidents. Our conclusions didn’t discovered any connection between age and number of crashes. Any connection between gender and crushes wasn’t found. Winter and Dodou (2010) noted that boys tend to have more accidents rather than girls, but girl do more lapses than boys while driving. This hypothesis wasn’t proved; thus, gender didn’t affect on number of accidents or mistakes.

Plumert and Kearney (2014) concluded that children cannot estimate the speed of cars and are more oriented to distance. A study was conducted with a focus group of 5–15-year-old using virtual reality. The research showed that the older children were the more experienced cyclists. They did not stop or slow down before the crossing and estimated the distance to cross on the way. In contrast, younger children were more likely to stop before an intersection. We have revealed that the older participants didn’t stop on the sign “STOP” and before changing traffic light, they stopped on closer distance rather than younger group. Thus, the age is correlate with experience and self-confidence.

A study has shown that older cyclists have significantly lower error scores and fewer traffic violations. Young cyclists have lower values for positive cycling behaviour than older people (Useche et al., 2021). However, in our case we can observe that younger cyclists stopped further from traffic light and always stopped at “STOP” sign rather than older participants. Thus, younger age group was more careful rather than older, which doesn’t prove the conclusion of Useche and colleagues’ study (2021). The authors suggest that errors are more related to cycling skills than to perceptions of risk, and may occur equally in both genders. We came to the same conclusion, where wasn’t found any relations between gender, mistakes, experience and crahes.

Given the CBQ (Cycling Behaviour Questionnaire), the strongest association was between errors and cycling experience. Thus, participants who rated themselves as more experienced reported fewer memory or attention errors when cycling. This isn’t consistent with the results of the DBQ (Behavioural Behaviour Questionnaire), which showed that people who tended to have more experience made fewer errors while driving (McIlroy et al., 2022). Oldered (2016) found that pre-accident experience is valuable in that it provides signals to prevent accidents in future cases. We found this Hypothesis isn’t right, because children who had crashes in past 3 years, did mistakes or crashes into vehicles in simulation, while participants who testified about no crashes in 3 years, as well had some mistakes.. Thus, with the help of prevention, the number of traffic cases in real life can be reduced.

Our participants found cars, pedestrians, houses, traffic of cars and general realism of experiment as “neutral”, which agrees with Zeuwts and colleagues’ study (2023). In their experiment children as well estimated houses, trees, streets, and cars as “quite realistic”. Only movement of pedestrians they estimated as “below realistic” because they found it jerky, if compared to real life, which consistent with our findings. In our experiment participants noted that movement of pedestrians was “not realistic”. Zeuwts came to conclusion, that gender didn’t affect on the children answers. We found that nor gender, nor age didn’t have any correlation with realism questions. In our experiment participants estimated general reality of simulation as “neutral”, which came up as well with Zeuwts et al. (2023) study.

On such points as headache, difficulty concentrating, nausea, “full head”, having to burp, participants didn’t have any discomfort, however most common symptoms were general discomfort, tired eyes and sweat, which testified as well the Zeuwts study (2023). In their experiment children mostly felt general discomfort, which was caused of HTC Vive and VE.

The t-test showed that general malaise after or during the experiment was independent of gender. This means that even though the data set of girls and boys gave different answers, there was still no correlation between gender and feelings of nausea. Only 9 had mild symptoms of general sickness and 39 had none at all. The correlation between age and general sickness was tested in a simulation experiment. No correlation was found after statistical analysis. Our results testified as well Zeuwts and colleagues’ study (2023).

As a conclusion, girls estimated themselves as they reacted on events in simulation as “good”, while boys tend to think they overcome as “excellent” with all events. Although, the meanings of boys and girls are unequal, there was no correlation between gender and self-reported reaction.

9 LIMITATIONS

During the experiment the Bluetooth connection sometimes was lost, therefore delays on acceleration and deceleration appeared. It led to some outliers, as very high speed, crashes into every object, unusual SDLP and other incorrect meanings of data. Due to lost connection, for the further analysis 2 participants were excluded because of unusual meanings of data.

Another factor is limited time to experiment. It lasted only 9 days, so only 51 people participated in experiment. Due to time limitation some other interesting solutions weren't included in analysis. For instance, CBQ and its correlation between age and gender weren't provided and held.

The next limitation comes from number of participants. Due to excluding two people from experiment, less data was analyzed. It is essential to have at least 100 participants to figure out correlation and find potential connection between factors. At some point it was unclear whether factors have correlation because only week connection existed. Some factors as gender which according to literature supposed to be connected with speed, mistakes or risky behaviour, weren't connected after all.

It couldn't be seen clear correlation or tendency among boys of 15 years old, because this group was represented only 1 boy, which is insufficient for making any conclusions about 15 years old in general.

Another limitation is very innovative topic. Because it's new, not many literature was found. Some spots were unclear, existing literature provided data mostly about adults, and not about children. In other words, investigation of children cycling behaviour is unique and unexplored topic.

The language can be referred to last limitation. The experiment was held in Dutch, and some literature was as well in Dutch, hence for better understanding some translating programs were used.

10 RECOMMENDATIONS

The recommendations follow from the limitations. For the future research it is better to ask more than 100 people to participate, because statistical significance and correlation will be better seen when there are more people. As many publications are considering adults and their cycling behaviour, it might be interesting to ask different age groups to participate in experiment and after compare the results. Another interesting point is to ask participants to fill in CBQ (Appendix 1) and as well compare self-reported results to simulation results. As a final point, it can be hold real experiment to check the tendency of behaviour from self-reported to simulated and to real, because sometimes due to circumstances, behaviour in real life and in simulated environment could be differ.

11 CONCLUSION

To sum up, 49 participants were taken for the experiment. 23 boys, and 26 girls. The age was ranged from 11 to 15 years old. The average age of boys and girls was 12 years old. 2 participants from 51 were excluded because of outliers. Some data as giving priority to car and pedestrian were excluded as well due to incorrect recording. The experiment was divided into 2 parts: first is simulation, where children rode a bicycle regarding the concrete scenario, and second was post questionnaire to figure out any symptoms of sickness, feeling of realism and self-reflection.

It was checked correlation between gender, age, experience, breaking rules in past 3 years, stopping at orange light and “STOP” sign. The stopping distance was as well checked factor. It revealed that the older participants were more risky, often broke rules and felt more confident, rather than younger participants. Hence, experience, risky behaviour, braking traffic rules and traffic accidents have direct correlation to age. Those children, who had accidents by bicycle in past 3 years did mistakes and crushed into vehicles into simulation at the same level, as participants who didn’t have those experience.

However, the statement that younger participants did more mistakes than older one, didn’t testified. We revealed that the younger was person, than further he stopped from the event. For instance, older participants mostly stopped closer to traffic light and their distance was very short. Other results testified the literature. Only the connection between gender and other factors wasn’t found. Thus, it might be helpful for future research to extend experiment and ask more people to participate to have more reliable data.

Finally, if we compare our results to research sub-questions, we can clearly see, that there is no correlation between gender and cycling behaviour; breaking rules in past 3 years didn’t correlate with average speed in experiment; stopping distance don’t correlate with the gender. The correlation which we found was related with age and cycling behaviour, however older cyclists were riskier, rather than as it was assumed initially. Breaking rules in past 3 years had mild correlation with crashes into vehicles in the experiment, and age is positively correlated with stopping distance, where olders tended to stop more close than youngers.

The second part of experiment consisted of questionnaire. Participants were asked to fill in the self-reported questionnaire to figure out realism of the simulation. Mostly participants rated experiment as neutral. The answers were independent on age or gender. The less realistic rate was awarded to movement of pedestrians. Children estimated it as not realistic. Other variables, as traffic and cycle path were rated as “realistic” or “quite realistic”. All the results didn’t correlate with gender or age, which means that the answers were the same within girls and boys at different age groups. Hence, the study showed that boys and girls tend to estimate experiment in general as neutral and it didn’t correlate with age or gender (6th research sub-question).

As experiment was in simulated environment, participants might have sickness symptoms. Although, headache, difficuilty concentrating, nausea, “full” head, dizzy (eyes open) and having to burp were ranged as the strongest, mostly participants felt the general discomfort. Only 9 people had mild symptoms and 1 person complained he had a moderate symptom of general discomfort. The rare symptoms were upset stomach and having to burp.

Returning to the research sub-questions, participants had simulation sickness and it wasn't related with gender and age. Thus, it can't be seen that girls had more or less symptoms effect, than boys. Among the 11-year-old group, both girls and boys had only mild symptoms of simulated malaise. Sweating was the most common symptom among the 12-year-old boys and had little effect. Eye strain was the most frequent symptom among girls with almost invisible manifestation. The 13-year-old boys showed greater susceptibility to symptoms than the girls. They experienced slight difficulty in concentrating and mild general discomfort. Girls in the 13-year-old group reported eye strain but also only mild symptoms. In the 14-year-old group the boys only noticed sweating and a feeling of a "full" head but these were mild. The girls had mild symptoms of a general feeling of discomfort. In the final age group of 15, mild eye strain was observed in the boys, while the girls only had mild symptoms of headache and general discomfort.

The last part of questionnaire was aimed to figure out self-reaction on events in simulation. Children reported that such events as pedestrian crossing the road (with zebra and without zebra), and intersections with traffic lights were challenging. Their answers about reaction were ranged from very bad to bad. However, in general, they estimated their reaction on the whole simulation, as neutral.

Returning to our research sub-questions, it was noticed the tendency, that boys tend to estimate themselves reaction on events as excellent, while girls thought they reacted good. Although, the data seems to be different, statistical analysis didn't find any correlation between gender and self-reaction. Thus, in general, boys and girls had the same reaction on events, and it ranged from good to excellent. Girls and boys had a better reaction to intersections with traffic lights. Among each age group (from 11 to 15) the most difficult event was suddenly departing cars.

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APPENDIX 1

CBQ for adolescents in Dutch (Useche et al., 2021)

Nummer	Inhoud	Frequentie
CBQ2	Fietsen tegen het verkeer in waar het niet mag	0 1 2 3 4
CBQ3	Zig-zaggen tussen auto's wanneer ik me op een gemengde rijbaan bevind	
CBQ4	Mogelijk belemmerende zaken, zoals gsm, eten, bagage in de hand houden tijdens het fietsen	
CBQ5	Het gevoel hebben dat ik soms te snel rij	
CBQ6	Oversteken wanneer er geen verkeer is, zelfs al staat het licht op rood	
CBQ7	Een passagier op de fiets vervoeren zonder daar voorzieningen voor te hebben	
CBQ8	Conflict hebben over snelheid of 'racen' tegen een andere fietser or automobilist	
CBQ9	Onopzettelijk de straat oversteken zonder te kijken, waardoor een voertuig bruusk moet remmen om een aanrijding te vermijden	
CBQ10	(Bijna) een voetganger of fietser aanrijden omdat ik te weinig aandacht besteed aan het verkeer rondom me	
CBQ11	Bruusk remmen waardoor ik bijna een ongeval veroorzaak	
CBQ12	Overstekende voetgangers niet opmerken wanneer ik afsla	
CBQ13	Niet remmen voor een stop-of voorrangsbord, waardoor ik bijna een voertuig of voetganger aanrijd	
CBQ14	Heel bruusk remmen op een glad oppervlak	
CBQ15	Uit verstrooidheid merk ik niet op dat een voetganger wilt oversteken op het zebrapad, waardoor ik hem of haar niet de kans geef om over te steken	
CBQ16	Niet opmerken dat een geparkeerd voertuig wil vertrekken waardoor ik bruusk moet remmen om een aanrijding te vermijden	
CBQ17	Wanneer ik rechts rij, merk ik niet op dat een passagier uit een voertuig of bus wil stappen waardoor ik bijna tegen hem or haar aan rij	
CBQ18	Een voertuig proberen in te halen dat al aangegeven heeft dat het zal afstaan, waardoor het voertuig moet remmen	
CBQ19	Een bocht verkeerd inschatten waardoor ik tegen iets aanrij op de weg of waardoor ik mijn evenwicht verlies	
CBQ21	Het niet bewust zijn van de toestand van de wegen en vallen over een hobbel of put	
CBQ22	Verschillende verkeerstekens verwarren en niet op de gepaste situatie reageren	
CBQ23	Proberen te remmen, maar de remmen niet goed kunnen gebruiken omdat mijn handen niet goed gepositioneerd zijn	
CBQ24	Stoppen en links en rechts kijken voor ik een hoek afsla of een kruispunt oversteek	
CBQ25	Proberen niet te snel fietsen om te vermijden dat ik verrast word door abrupte obstakels of dat ik bruusk moet remmen	

CBQ26	Zorgen voor een veilige afstand tussen mezelf en andere fietsers of voertuigen	
CBQ28	Vermijden te fietsen wanner het slecht weer is	

APPENDIX 2

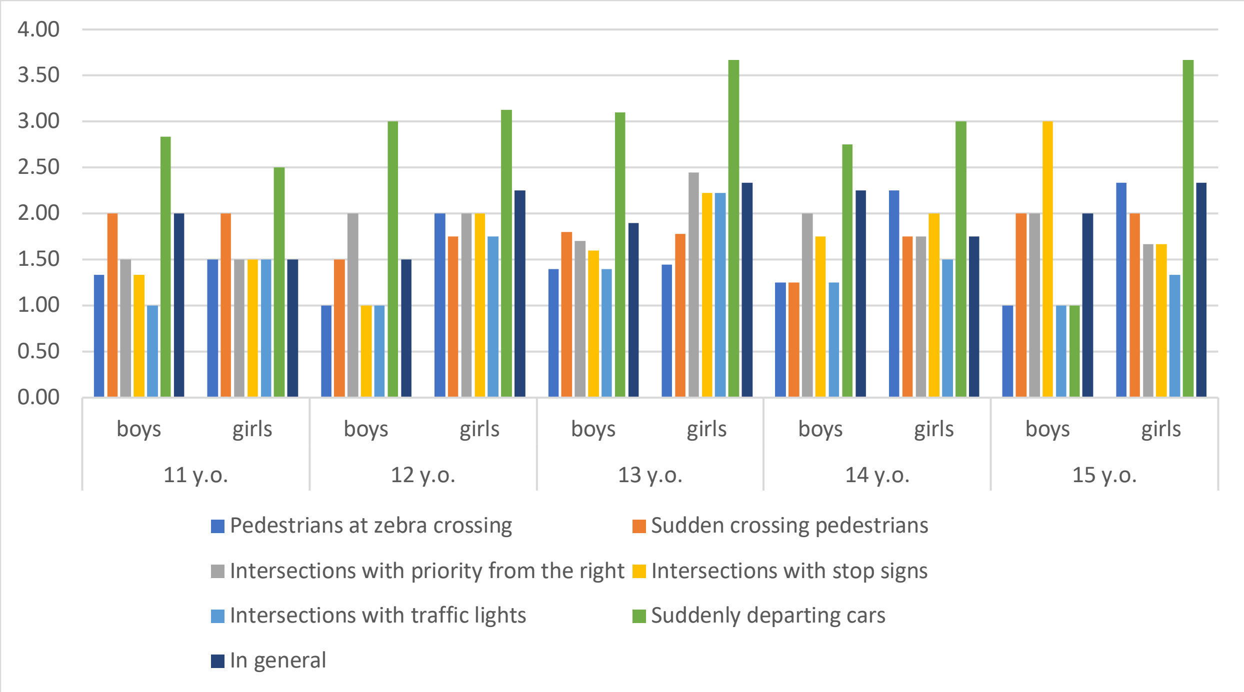
Existing studies with the bicycle simulator in the literature (Wintersberger et al., 2022)

Reference	Sensors	Actuator	Simulator type	Visualisation	Research purpose
Mittelstaedt, Wacker, Stelling, 2018	Speed, Steering, Braking	-	Stationary bicycle	HMD, Screen	Simulator Sickness Investigation
Herpers et al., 2008	Speed, Steering, Braking, Fork, Inclination	Motion Platform	(Active) Motion-based bicycle	Multi-screen	Bicycle simulator development
Löchtefeld, Krüger, Gellersen, 2016	Speed, Steering	Airstream	Stationary ergometr	HMD	Effective training
Hernández-Melgarejo et al., 2020	Speed, Steering, Braking	Handlebar, Braking	Stationary bicycle	HMD	Bicycle simulator development
von Sawitzky et al., 2020	Speed, Steering	-	Stationary bicucle	HMD	Traffic safety
Yamaguchi et al., 2018	Speed, Steering, Braking	Tilting	(Active) Motion-based bicycle	Multi-screen	Traffic safety
Matviienko et al., 2018	Speed, Steering, Braking	Visual, tactile, auditory feedback	Stationary bicycle	Projection	Traffic safety
Batcir et al., 2021	Speed, Motion Capture system	Motion Platform	(Active) Motion-based ergometer	Screen	Training and health
Byrd, 2015	Speed, Steering	Resistence	Stationary bicycle	HMD	Bicycle simulator development
Ullman et al., 2020	Speed, Steering	-	Stationary bicycle	HMD	Urban traffic planning
Sun, Qing, 2018	Speed, Steering, Braking	-	Stationary bicycle	Screen	Bicycle simulator development
Kaths et al., 2019	Speed, Steering	-	Stationary bicycle	Multi-screen	Traffic planning and user modeling
O'Hern, Oxley, Stevenson, 2017	Speed, Steering, Braking	-	Stationary bicycle	HMD	Traffic safety

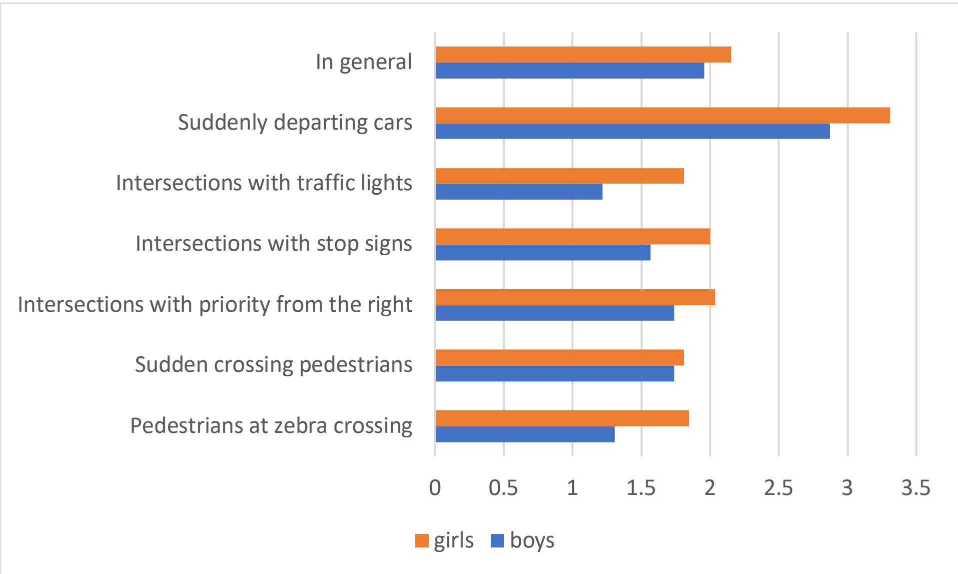
Nazemi et al., 2021	Speed, Steering, Braking	Resistence	Stationary bicycle	HMD	Traffic safety
Melo et al., 2016	Speed, Steering, Braking	Airstream	Stationary bicycle	HMD	Simulator Sickness Investigation
De Souza e Almeida et al., 2019	Speed, Steering, Braking, Body, Weight	Airstream, Haptic response	(Passive) Motion-based bicycle	HMD	Bicycle simulator development, User experience investigation
Shoman, Imine, 2021	Speed, Steering, Braking	Airstream, Haptic response, Steering response, flywheel	(Passive) Motion-based bicycle	Multi-screen	Bicycle simulator development
Hamad, 2021	Speed, Steering via button	Airstream	(Passive) Motion-based bicycle	HMD	Bicycle simulator development, Traffic safety

Appendix 3

1. Descriptive analysis of average children's reaction on events in simulation from 11 to 15 y.o. (own elaboration in Excel)



2. Descriptive analysis of average reaction between girls and boys, where 1 is excellent, 5 is poor (own elaboration in Excel)



3. Correlation between age and accidents in past 3 years (own elaboration in SPSS)

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	8.648[a]	4	.071
Likelihood Ratio	7.847	4	.097
N of Valid Cases	49		

a. 6 cells (60.0%) have expected count less than 5. The minimum expected count is .41.

4. Correlation between stopped for orange and gender (own elaboration in SPSS)

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance		Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p			Lower	Upper
StoppedForOrange_average	Equal variances assumed	7.492	.009	-1.281	47	.103	.206	-.05769	.04504	-.14830	.03291
	Equal variances not assumed			-1.364	25.000	.092	.185	-.05769	.04231	-.14483	.02944

5. Correlation between age and full stop at “Stop” sign (own elaboration in SPSS)

Correlations

			Hoe oud ben je?	FullStopAtSign_average
Spearman's rho	Hoe oud ben je?	Correlation Coefficient	1.000	-.293*
		Sig. (2-tailed)	.	.041
		N	49	49
	FullStopAtSign_average	Correlation Coefficient	-.293*	1.000
		Sig. (2-tailed)	.041	.
		N	49	49

*. Correlation is significant at the 0.05 level (2-tailed).

6. Correlation between accidents in past 3 years and crashes into vehicles in simulation (own elaboration in SPSS)

Correlations

			Hoe vaak was je betrokken bij een verkeersongeval met de fiets de afgelopen 3 jaar?	CrashVechile_average
Spearman's rho	Hoe vaak was je betrokken bij een verkeersongeval met de fiets de afgelopen 3 jaar?	Correlation Coefficient	1.000	.239
		Sig. (2-tailed)	.	.098
		N	49	49
	CrashVechile_average	Correlation Coefficient	.239	1.000
		Sig. (2-tailed)	.098	.
		N	49	49

7. Correlation between age and stopping distance at orange (own elaboration in SPSS)

Correlations

			Distance_0outliers_StoppedOrange	Hoe oud ben je?
Spearman's rho	Distance_0outliers_StoppedOrange	Correlation Coefficient	1.000	.290*
		Sig. (2-tailed)	.	.043
		N	49	49
	Hoe oud ben je?	Correlation Coefficient	.290*	1.000
		Sig. (2-tailed)	.043	.
		N	49	49

*. Correlation is significant at the 0.05 level (2-tailed).