UHASSELT

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School of Transportation Sciences

Master of Transportation Sciences

Master's thesis

Impact of traffic education program for international students on simulated cycling behavior in Belgium

Gaspard Ukwizagira

Thesis presented in fulfillment of the requirements for the degree of Master of Transportation Sciences, specialization Traffic Safety

SUPERVISOR :

Prof. dr. Ariane CUENEN

MENTOR :

De heer Thomas STIEGLITZ

2024
2025

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www.uhasselt.be
Universiteit Hasselt
Campus Hasselt:
Martelarenlaan 42 | 3500 Hasselt
Campus Diepenbeek:
Agoralaan Gebouw D | 3590 Diepenbeek

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Preface

It is better to prevent than to cure." That ancient wisdom speaks powerfully in the modern world of developing technology and changing city transportation patterns. In a world where safety, health, and sustainability are at stake, knowing and avoiding road traffic crashes is an issue of global priority. With the advent of electric cars, intelligent mobility systems, and vision-zero strategies to address road fatalities, greater emphasis has been placed on developing safer systems for drivers and other vulnerable groups, such as cyclists. With cycling growing as a primary mode of transport with its health and environmental benefits, the safety of cyclists, especially foreign or visiting cyclists, becomes even more critical. International students studying in Belgium, particularly in towns like Hasselt, primarily move around on bicycles. However, most come from countries with dissimilar or poor cycling infrastructure and cycling culture regarding road safety.

Infrastructure and cultural variation increase risk, misinterpretation, and misguided road behavior. This study investigates the possibility of immersive traffic education in stimulating international students' cycling behavior within a secure virtual world through a bicycle simulator. With implications for how simulation-based training may reduce risky behaviors and maximize safety outcomes, this study aims to bridge the knowledge-behavior gap.

This research project aims to support a more open and proactive approach to road safety that addresses the heterogeneity of road users and the role of education in fostering responsible behavior.I want to thank the international students who participated in this study, my supervisors for their guidance, and Hasselt University for permitting the use of resources and platform to conduct this important project.

Summary

The master's thesis titled "Impact of a traffic education program for international students on simulated cycling behavior in Belgium" examines how structured training through the use of a cycling simulator can improve traffic awareness and safety of behavior of non-Belgian international students, given that they are not familiar to Belgian cycling law. The study was conducted at Hasselt University, targeting non-Belgian students from nations with adverse cycling infrastructure or other road safety norms. Since Belgium is such a cycling culture and relatively complex traffic environment, these students are generally at greater risk of traffic accidents due to unfamiliarity with local signs, road hierarchies, and use of shared paths.

Education targeted to test if it would have an impact was tried by splitting the 31 participants into two groups: a Control Group with 15 participants and an Experimental Group with 16 participants. The CG rode simulators without educational intervention, whereas the EG received scenario-based training and feedback during the simulator ride. Pre- and post-test questionnaires and simulator evaluations were both administered. Results of these tests, combined with thorough statistical analysis, found that EG participants had significantly greater understanding of Belgian traffic signs, better behavioral responses to simulated traffic problems, and better decision-making in complicated road scenarios during the post-test.

The pre-test period showed the chief problems of mass misperception of certain traffic rules. Many also mentioned previous experiences of minor bicycle crashes or close calls, typically because they were unfamiliar with the infrastructure or right-of-way rules. While helmet usage was low among the group overall only 41.9% reporting use on a regular basis, the study found that systematic training dramatically increased awareness of safety among the participants and reduced simulator error rates. Questionnaire findings reflected these trends, but between-group differences were not significant. Age and history of accidents impacted demographic variables to some extent, but gender did not predict unsafe behavior reliably. Participants rated the simulator as realistic and valuable, and they reported that EG participants had increased confidence and safety awareness. Despite certain drawbacks like small sample size, brief study period, and occasional technical issues, the findings validate the effectiveness of immersive, feedback-based simulation training. The study recommends integrating such specialized programs into university induction or local road safety programs to maximize cycling security among international students in hazardous traffic conditions, like Belgium.

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List of abbreviations

AV: Approaching vehicles

BFG: Bicycles for Growth

CBQ: Cycling behaviour questionnaire

CG: Control Group

DTA: Distance to Arrival

EG: Experimental group

IMOB: Instituut voor mobiliteit

SPSS: Statistical package for the social science

SS: simulator sickness

VR: Virtual reality

1. General Introduction

1.1. Introduction

Bicycle use has grown significantly in recent years due to increasing awareness of the environmental impact of transportation and efforts to reduce emissions. As cyclists represent a growing percentage of road users, understanding their behavior has become crucial for road safety. Cycling is essential due to its positive impacts on society, the environment, and health, which makes it a necessary mode of transport (Mueller et al., 2015). Many countries have been promoting cycling as a daily mode of transport. In addition, compared to other modes of transport, cycling is considered as a low-cost mode; it helps reduce road congestion by reducing the number of road users traveling using vehicles (Parkin & Meyers, 2010). Cycling is recognized as a clean mode of transport and an essential part of an inter-modal plan for sustainable urban travel; it is also considered a good strategy for healthy cities (Saelens et al., 2003).

Cycling, which includes track cycling, road cycling, and mountain biking, offers numerous health benefits. These include increased fitness, reduced risk of heart attack, weight loss, and stress reduction (Tang et al., 2007). In 2016, an estimated 40,000 cyclists died in road crashes globally, making up 3% of all road fatalities (WHO, 2018). The World Health Organization (WHO) highlights that cyclists, as vulnerable road users, are disproportionately represented in road injuries and fatalities, particularly in low- and middle-income countries. Cyclists remain particularly vulnerable in traffic, being the only road user group where fatalities have not decreased since 2010. In 2022, approximately 2,000 cyclist deaths were reported in Europe, accounting for one in ten road fatalities. Additionally, the share of serious injuries from crashes involving cyclists increased from 7% in 2010 to 9% in 2019, indicating a growing concern for cyclist safety on the roads (European Commission, 2021).

Cyclists are at greater risk on roads compared to motor vehicle occupants due to their lack of physical protection and the lower mass and stability of bicycles (Prati et al., 2017). The increasing use of this ecological means of transport requires a specific assessment of cyclist safety in terms of traffic flow, human factors, and cycling infrastructure. As vulnerable road users, special care is needed for them. Cycling is a critical means of transport, particularly in smaller towns and cities like Hasselt and Diepenbeek in Belgium. Students worldwide come to Hasselt University to pursue higher education, often from countries without a cycling culture. Practical knowledge of cycling among students from countries outside Belgium must be improved despite the provided orientation sessions to familiarize them with cycling and traffic safety rules in the new environment.

1.2. International people cycling in Belgium

International students from European and non-European countries have divergent road safety experiences and behaviors. The applied traffic rules, formal and informal, in Belgium, are unknown to many, and no specific traffic education program is obliged to follow. The most common modes of transport for students are cycling, walking, and public transport. Safe road user behavior depends on understanding road signs and markings that are not immediately apparent. Road users need to understand what to expect in traffic situations, such as who has the right of way at intersections, cycling direction, and the location of pedestrian footpaths. Furthermore, ongoing construction on the road to the university has led to multiple directional changes in the cycling and walking path and the relocation of bus stops. All in all, international students are, due to a lack of knowledge and experience, facing a higher risk of being involved in road incidents and more restricted in their movements.

1.3. Cycling simulator

Cycling simulators have been recognized as a useful tool to study road users behavior in alternative forms, such as databasing on a safe environment, enhancing the road safety in all its involved populations and designing analyses for innovating new solutions on cycling. Similator depicts the road network from a real-world urban environment (Hamad, 2021). With the Cycling Simulator, designs can be evaluated multiple times. It can highlight problems or implications with how the new space could potentially be experienced by people that should have been front and centre in minds when they were sketching out the installation. Bike simulators lend themself to address human factors research questions concerning the behaviors of vulnerable road users in relation to various types of roads and traffic (O'Hern et al., 2017). It also enhances cycling behavior and riding safety awareness using a cycling simulator to experience virtual accidents in a virtual space with training/educations (Tsuboi et al., 2018). Although there is a broad advantage to cycling simulator during practice but there are some shortcomings as well like in VR where users can experience motion- or cyber-sickness, which gives symptoms of vertigo, headaches and nausea with potential side effects. You feel sick right as you enter the VR space. The most popular explanation for this is the sensory conflict theory, which postulates that the sickness stems from a disparity between what your eyes perceive and what your vestibular system detects (LaViola, 2000).

1.4. Problem statement

Road traffic accident continuously increases worldwide, and Vulnerable Road Users (VRUs), such as cyclists, are ever more susceptible to crashes and injuries. Cyclists are one of the main categories of road users, mostly exposed to road accident risk (Acerra et al., 2023). Safe cycling has traditionally received less emphasis in road safety education and training than motor vehicle driving, contributing to higher instances of risky riding behaviors and conflicts with other road users. This discrepancy highlights the need for more robust and targeted educational programs for cyclists to promote safer riding practices (Ma et al., 2019). Bicycle crashes are significantly under-reported compared to motor vehicle crashes, with an international survey showing that only about 10% of bicycle crashes are reported to the police. Factors influencing reporting levels include the crash type, the vehicles involved, and injury severity (Shinar et al., 2018). Underreporting is especially high when no motor vehicle is involved, such as in collisions with obstacles or other cyclists. Non-fatal crashes are more likely to go unreported, and even fatal bicycle crashes without motor vehicle involvement are sometimes missing from police records. This underreporting should be considered when assessing cyclist road safety (Schepers et al., 2017). The greater probability of a cyclist being injured in the road crashes compared to motorists makes some people uncomfortable with this mode of transportation (Reynolds et al., 2009). The cyclists lose their balance and are less stable as inexperienced bike riders and obstacles on the cycle path take them out. Cyclists often ignore the traffic regulations and demonstrate unpredicted behaviour by other road users. This results in a high crash rate of cyclists compared to other road users (Wegman et al, 2012).

1.5. Objectives

The main objective of this study is to evaluate the cycling behavior of new international students at Hasselt University who come from worldwide, except Belgium, by using a cycling simulator.

1. Investigate the knowledge of international students on traffic rules and infrastructure in Belgium
2. To assess the impact of training before and after being educated on cycling behavior.

3. To assess participants' perceptions of the training process, including its effectiveness, clarity, and engagement

4. To gather the necessary information related to bicycle accident data for international students

1.6. Research questions

Research questions are linked to objectives; this study is being conducted to answer the following research questions:

1. How many international students were involved in the crash?
2. Do international students understand Belgium's traffic rules and cycling infrastructure?
3. How does the cyclist behave before the education?
4. Does education in the cycling simulator positively affect cycling behaviours?
5. What is the overall opinion of the participants of the training?

1.7. Study area

Hasselt is the capital of the Limburg province, Flanders Region, with a population of 80611 in 2023 (Hasselt in Cijfers). The town is situated in the northern part of Belgium, about 35 km west of the national border between Belgium and the Netherlands and 20 km north of the Dutch French language border, which separates Belgium into a northern part (Flanders) and a southern part (Wallonia). The participants in this study will come from the Flanders region, Antwerp, Hasselt, Ghent, and Diepenbeck, but specifically for the experiment, they are international people from Hasselt.

Figure 1: Location of the study area (Source: google image)

2. Literature review

2.1. General Overview

Vehicle simulators, including those for automobiles, bicycles, flights, tanks, and ships, have been extensively developed and utilized for multiple purposes. These simulators include testing designs, evaluating environments, training operators, and providing entertainment (Guiso, 1995). Experimenting in real environments can be costly and biased due to uncontrolled variables. In contrast, simulators enable the detection of cyclist and road user behavior in various riding situations while controlling variables and avoiding real-world risks. Bicycle simulators are designed for various purposes, including training, sports, virtual reality immersion, bicycle dynamics modeling, and evaluating cyclists' performance and behavior (Shoman & Imine, 2021).

With the growing popularity of bicycles as a sustainable transport mode in the past two decades and their being environmentally friendly compared to motorized transport, bicycle facilities have relatively less development, research, and understanding. In recent years, the bike simulator (BS) has provided a reasonably realistic environment for conducting research in cycling, and it is capable of simulating real-world environments. It also gives insight into understanding a bicycle facility's design and cyclists' behavior (Ansariyar et al., 2022).

The use of immersive technologies, especially those for capturing data in a controlled dynamic environment, is prevalent and helps inform any necessary design based on user behaviour. No data as to the ecological validity of this method is available, so its uptake in transport mode choice modeling has been limited. Participants behave differently when shown a choice scenario in non-immersive and immersive settings. In particular, cycling in an immersive setting is characterized by a higher degree of engagement (Bogacz et al., 2020). Bicycle simulators for traffic safety research are designed to evaluate cyclists' behavior. The focus of these systems is to elicit natural behavior by immersing the user in a virtual reality environment (VRE) and providing realistic stimuli for cyclists to react to similarly as they would in real life. Immersion and feeling in the VRE are essential for realistic behavioral responses (Slater et al., 2009).

In the experiment, 27 participants cycled through a no-signal trumpet three-way intersection inspired from an intersection in Gothenburg, Sweden. For instance, they rode in a separated bike lane down the street and crossed through 12 times as they interacted with an AV that approached from their right. Cyclists usually stopped pedaling to brake and look at the vehicle approaching before they made a decision on whether to yield or cross. The present study was undertaken to find out the Distance to Arrival (DTA) and Intersection Visibility (IV). The DTA, duration of looking, and the tricycle-pedaling activities were found to greatly influence decline-yielding decisions; on the other hand, visibility had a significant effect on brake-aimed deployments earlier in response as visibility increased. A reduction of the DTA values indicated that cyclists were less likely to cross first and led to more severe braking. These results can assist in establishing safe DTA limits for interactions between autonomous vehicles and cyclists (Mohammadi et al., 2024).

2.2. Comparison of the cycling simulator with other cycling scenarios

2.2.1. Description of cycling simulator with road cycling

A study with 40 experienced cyclists (22 males, 18 females) evaluated cycling behavior on a 4 km route in Stockholm and a simulated version of the route. Participants were divided into equal groups for on-site and simulator tests, with most on-site participants familiar with the route but none experienced with the simulator. Both environments featured various road types and involved the use of GPS. On-site tests began at KTH in Stockholm, while simulator participants completed a 4 km round trip, including an adaptation lap. After cycling, participants completed the NASA Task Load Index and a disease questionnaire to assess task demands, performance, and subjective perceptions. Visual tracking identified high distraction levels in the infrastructure, with pedestrian crossings highlighted as critical points. On-site, cyclists showed low inattention but often failed to notice traffic lights at crossings. In the simulator, cyclists were distracted by detailed buildings and often failed to yield to wheelchairs at crossings (Acerra et al., 2023).

According to Nazemi (2018) explored the use of immersive virtual reality (VR) combined with an instrumented cycling simulator to examine cyclists' perceived safety and comfort in a non-naturalistic environment in Singapore, focusing on how environmental properties and road infrastructure impact these perceptions. The study involved 40 participants, mainly university students, and the study showed that the average speed of the participants changes between scenes with different bicycle facilities, with the highest value for the segregated bicycle path. The braking and head movement activities also changed within each scene, significantly occurring more before arriving at the intersections. Questionnaire results showed that adding a painted bicycle path to a sidewalk increases perceived safety. Moreover, participants felt safest cycling on the segregated bicycle. This study faced two main limitations. First, the steering was locked, restricting participants to riding in a straight line. The steering wheel sensor was deactivated after the pilot phase revealed motion sickness among participants. This setup required participants to devote significant attention to maintaining position in VR, which distracted them from focusing on key aspects of the experiment. Second, the study lacked interaction between the participant (as the cyclist in VR) and other road users, due to technological constraints. These limitations impacted the realism and overall immersion of the VR experience, potentially affecting the study's findings on cyclist behavior.

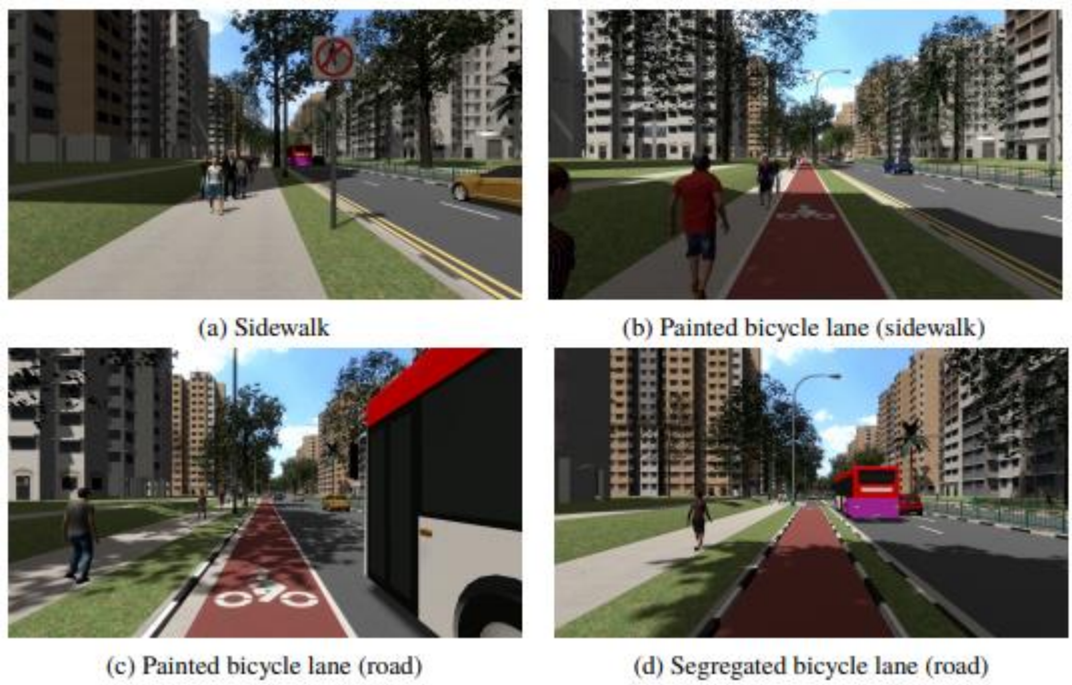

Figure 2: Four different treatments (Nazemi et al., 2018)

Real environment experiments are found to be the most representative of cyclist behavior and safety, but they tend to be very costly and risky; instead, simulators provide controlled, risk-free conditions (Shoman et al., 2020). In a previous study, Shoman & Imine (2023) validated the simulator by comparing real road cycling with a simulator in Stockholm; this was performed by 22 cyclists that cycled over an instrumented bicycle route divided into mixed traffic, separated lane and shared pedestrian-cyclist zones and with varying surface conditions. The experiment was then digitally re-enacted in Paris with 31 cyclists. Real-world average speeds were 12.45 km/h (snowy/icy) and 15.73 km/h (dry/wet), versus 14.34 in the simulator.

The simulator used 52% less power. Safety evaluations were similar; 59% felt safest in reality and in a different independent sample simulator environment (55%). These two studies in different places (Shoman & Imine, 2023) suggest that the simulator is reliable with regard to safety evaluations and route testing.

Haasnoot et al. (2023) introduced a bike system where a kinematic bicycle simulator is designed to provide a realistic cycling experience with direct balance control and freedom of motion, including steer, roll, yaw, and sway. The simulator utilizes Carvallo–Whipple bicycle model-based control for sway and yaw, alongside passive steer and roll, to enhance realism. The bike system was validated by comparing cycling behavior and subjective evaluations in scenarios with and without motion, against outdoor tests using an instrumented bicycle. Fifteen participants of varying ages and body masses performed straight-line cycling at speeds ranging from 5 km/h to 40 km/h and executed zig-zag maneuvers. Results show that users can successfully rely on existing cycling skills to use the simulator with motion. Objectively, in the kinematic sense, the simulator with motion performs similarly to an outdoor bicycle. Subjectively, the simulator performs better with motion and is experienced by riders as close to real outdoor cycling.

2.2.2. Driving simulator

According to Ouimet et al (2011), driving simulators present a unique opportunity for research and industrial applications that is both subjectively reactive and objectively regular. The safety implications of new driving technologies are realized through car collisions, and determining the causes of these crashes is not always a simple process. While rich in insight regarding how drivers do all sorts of things across a variety of contexts, there is no experimental manipulation to make causal inferences. On the other hand, driving simulators use simulated scenarios and are more objective in measuring driver performance (Boyle & Lee, 2010). Simulator study could also determine the influencing factors (driver, vehicle, and road environment) in which driving safety can be enhanced (Boyle & Lee, 2010).

Considering the increasing capacity of modern computer systems, driving simulation is likely to continue changing and be of greater use through simulator testing areas within driver assessment, training, research, and entertainment. Organizations will have easier access to low-cost virtual reality applications. Although simulators can be widely used before driving, there are several questions that have yet to be answered in research. These involve simulator fidelity, simulator predictive validity, and simulator-to-real-world driving transfer, as well as simulator discomfort (de Winter et al., 2012).

2.2.3. Motorcycle simulator

In 1971, Dahl passed the first patent for a motorcycle simulator. This stationary simulator was originally built to teach people how to ride motorcycles. The simulator would allow the rider to practice starting, stopping, steering, braking, and changing gears. Being, though no visual perception of the surrounding world (Wildner & Diermeyer, 2023).

Grottoli et al., (2022) conducted a study in Leuven (Belgium) to for the objective to explore the subjective (what the rider felt) and objective (what actual dynamics were presented to the rider by the simulator) performance of a new riding simulator focusing on low-speed (0–10m/s), both with and without motion of the platform, for three types of maneuvers: namely acceleration from standstill, braking to standstill and turning at constant speed. After every maneuver, participants rated a brief evaluation of realism for the simulator, followed by detailed feedback on every motion condition. Data from an instrumented motorcycle enabled measurement of behavioral fidelity.The experiment was conducted with 12 participants who were all employees of Siemens Digital Industries Software in Leuven (Belgium), where the motorcycle simulator is situated. The sample included only men with a mean age of 35.8 years (SD 8.7), all of whom held a motorcycle driving license (AM, A1, A). Prior to the experiment, half of the sample stated they had never ridden a motorcycle in the 12 months preceding (non-motorcyclists), whilst the other half reported rides from once a month to multiple times per week (motorcyclists). The participants were able to keep their balance and from falling while executing these maneuvers. Some forms of platform motion positively affected the subjective sense of presence, increased the perception of having rotated inwards around one's longitudinal body axis (roll tilt), and decreased verticality judgments. The simulator high-precise reproduction of real-world data in terms of behavioral fidelity, leading the performance realism and quality for braking maneuvers thanks to platform motion

Figure 3:The motorcycle simulator uses a head-mounted display to present the driving environment. The lower images represent a screenshot from the turning maneuver

2.3. Cycling accidents in Belgium

2.3.1. Accident in the European Union

In 2020, there were an estimated 758,000 road crashes, and 18,800 people were killed on the European Union roads (European Commission, 2022). Although the COVID-19 restrictive measures on passenger transport are primarily responsible for the drop in road deaths compared with 2019 (-17%), the absolute number of fatalities in EU countries remains of concern. Among the most vulnerable during traffic crashes, occupants of small vehicles such as passenger cars are included. Car occupants (drivers and passengers) accounted for 43% of all road deaths, meaning they still need more protection (Pawłowski et al.,2019).

Cyclists are vulnerable in traffic and constitute the only road user group where the number of fatalities has not declined in since 2010. In 2019, more than 2,000 road deaths among cyclists in Europe were reported by the police. This means that almost one in ten recorded fatalities in traffic is a cyclist. Furthermore, the share of serious injuries in crashes involving a cyclist did not decline: their relative proportion increased from 7% in 2010 to 9% in 2019 (European Commission, 2021). However, the volume of this share is probably much greater, due to under-reporting of these crashes (Shinar et al., 2018).

In the EU, cyclists are the only road user group that has not experienced a decrease in fatalities since 2010, recording between 1,900 and 2,100 annually. It is a dangerous job: cyclists in countries with large percentages of cyclist fatalities, such as the Netherlands or Denmark, Belgium, and Germany, also have higher than average cyclist mortality, reflecting (very) high use of bicycles. Similarly, the slowdown in cyclist deaths may partly be because cycling is gaining popularity, and there has also been insufficient infrastructure investment for safety (Swov, 2021). In 2019, almost half (47%) of cyclists killed were aged 65 and older, though a smaller share than for pedestrian fatalities (50%). Male cyclists were involved in 82% of cyclist fatalities. Crashes with car drivers, other cyclists, or pedestrians are all common causes of death for people on bikes, although many crashes involving only the rider are not reported. Nearly all of the cyclist fatalities (68%) were on weekdays, daytime, and overwhelmingly during the summer months. Most fatal cyclist crashes happened on urban roads (58%), and a higher proportion of these fatalities occurred at junctions (17% compared to 10% among all road fatalities) (Swov, 2021).

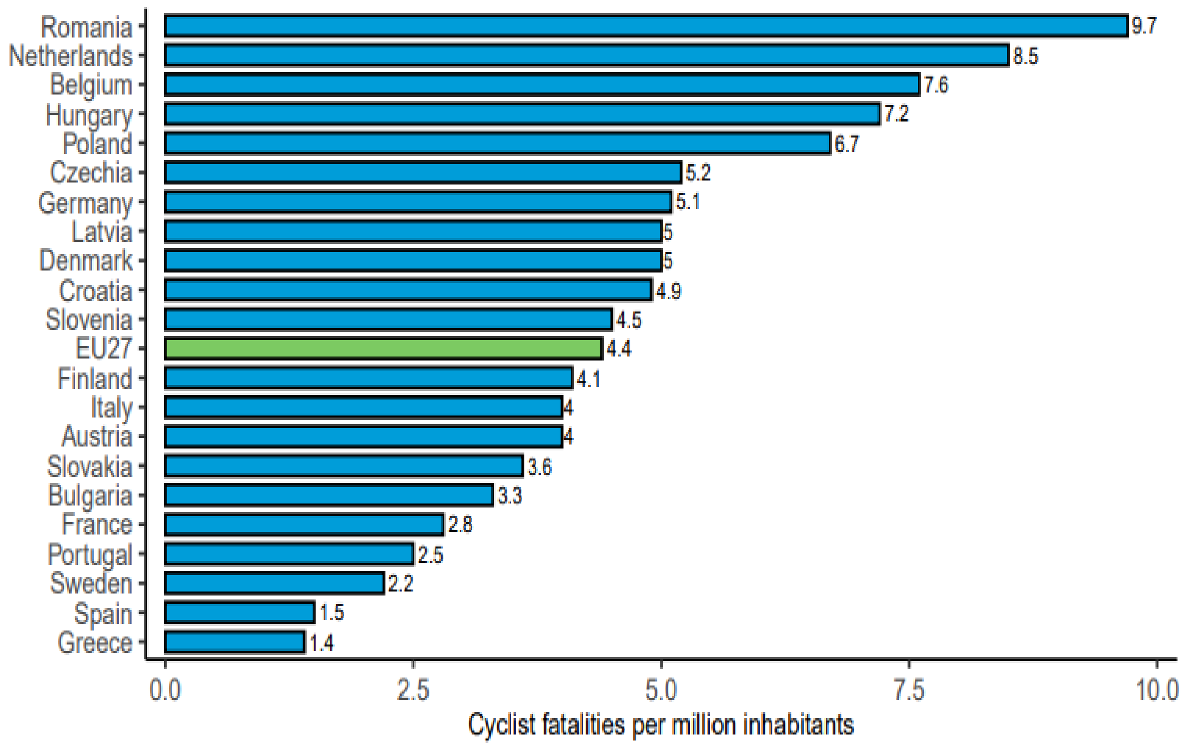

Figure 4: Cyclist fatalities per million inhabitants per country in the EU27 (2017-2019). Source: CARE, EUROSTAT

Mortality rates alone do not fully capture road safety differences across countries. High cyclist mortality might correlate with high overall road mortality. Thus, examining the proportion of cyclist fatalities within total road fatalities is also crucial. The Netherlands and Belgium remain in the top four for high shares of cyclist fatalities. Romania's high cyclist mortality aligns with its overall road mortality, whereas Denmark's share has increased. Germany ranks fourth in cyclist fatalities. The popularity of cycling in these neighboring countries (Netherlands, Belgium, Germany, Denmark) contributes to their higher shares of cyclist fatalities.

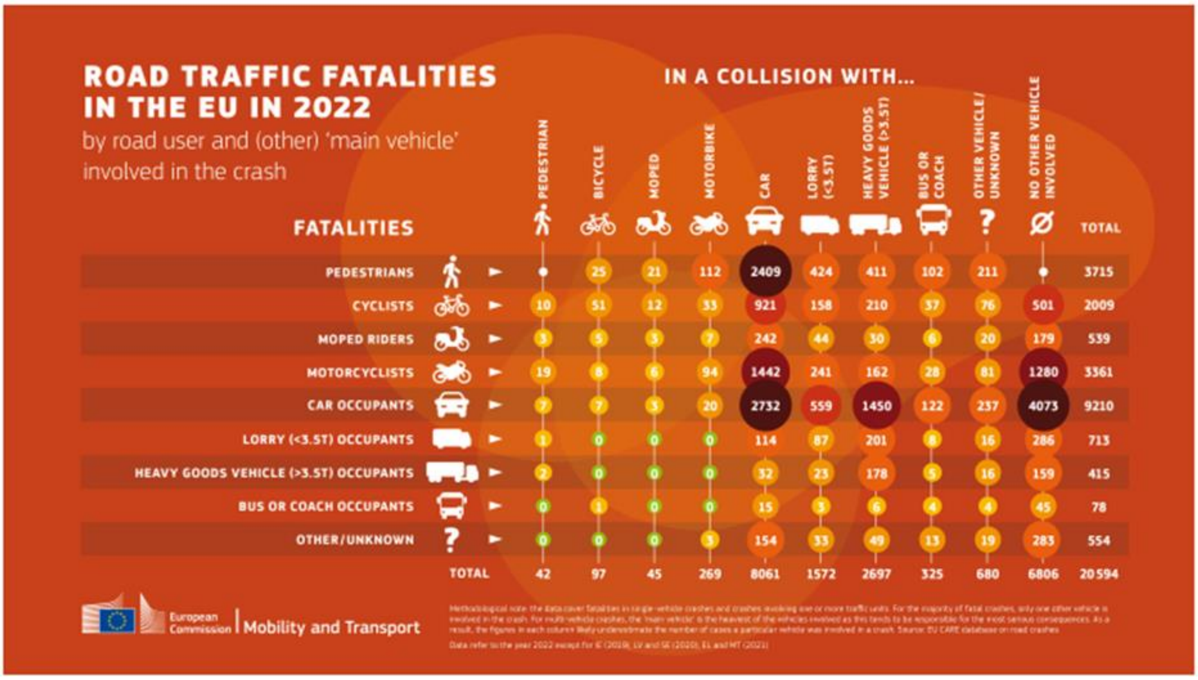

Figure 5:European Traffic Fatalities Matrix. Source: European Commission-Mobility and Transport

2.3.2. Accidents in Belgium

In Belgium, with approximately 11 million inhabitants, almost half of the population owns a bicycle (48%). Eight percent of all trips are made by bicycle. Each Belgian cyclist travels an average of 0.9 kilometers daily (European Cyclists' Federation, 2015). The popularity of cycling in Belgium is higher than in most of the other countries (6th place in the EU). However, it is still far below the goal. Moreover, there is a big difference between Flanders (the northern part of Belgium) and Wallonia (the southern part). A National Household Survey in Belgium in 2001 shows that only 6.4% of all cyclists live in Wallonia, while 91% live in Flanders (Belgian National Household Survey, 2001).

In Belgium cycling is most prevalent in Flanders (18%), followed by Brussels (4%) and Wallonia (2%). Flanders has a long-standing tradition of cycling as a sport and has recently seen an increase in cycling for commuting. The number of cyclists in Brussels nearly doubled since the COVID-19 crisis. Flanders also leads in the popularity of speed pedelecs (45 km/h), with about 12,000 registered in 2019, the highest in the Benelux/North Rhine-Westphalia region. Nationally, by early 2022, Belgium had 53,000-speed pedelecs registered (BikeRoadmap.Pdf, 2022).

Belgian statistics on bicycle accidents and damage are not very accurate, since many of them are never reported to the police or hospitals or insurance companies. While crashes involving only one bicycle form a substantial proportion of all bicycle crashes and can show relevant correlations with injuries, they are often not registered and therefore underestimated in official data (Aertsens et al., 2010). While there is much to recommend cycling, doing nothing to take drastic measures risks increases in injuries and fatalities from a relatively high level (Wegman et al., 2012). For now, though this mode of transport has still a lot to be improved in order to work properly.

The Flemish research "Onderzoek Verplaatsingsgedrag Vlaanderen" conducted from September 2012 to September 2013 mainly shows the cycling situation in Flanders and the Limburg province. 13% of all trips in Flanders were made by bicycle. However, it is only 6% of all kilometers in the region, while in Limburg, almost 9% of the kilometers traveled were done by bicycle (considering trips less than 1000km). On average, each Flemish person owns a bike, and 15% of the population uses it for daily purposes, while 31% of the residents use the bicycle 1 to several times per week. Regarding tourism, 46% of trips in Flanders were devoted to recreational traveling (with a destination point in Flanders). At the same time, in Limburg province, 60% of inhabitants use bicycles for tourism-related activities (with a destination point in Limburg).

In 2022, cyclist fatalities in Belgium increased by 16.9% compared to the 2017-19 average, while fatalities among car occupants, powered two-wheelers, and pedestrians decreased by 25.6%, 18.8%, and 4.5%, respectively. Road deaths among young people aged 0-14 significantly decreased by 38.5%. Belgium's road mortality rate was 4.6 deaths per 100,000 people, with a fatality risk of 0.7 deaths per 10,000 registered vehicles. The most at-risk age group were those aged 75 and above, with a mortality rate of 8.0 deaths per 100,000, followed by the 21-24 age group (Itf/rpa, 2023).

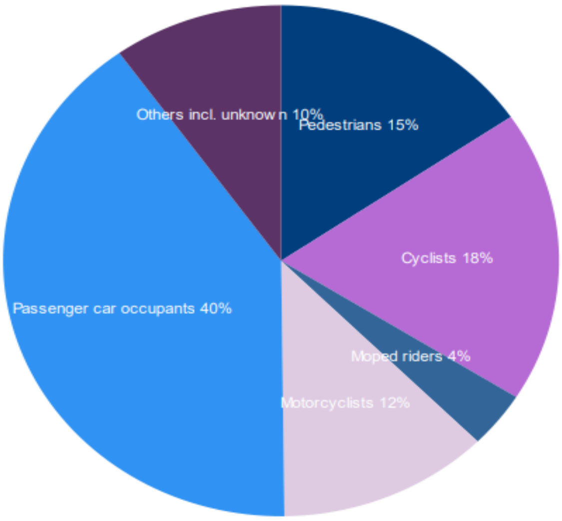

Figure 6: Road fatalities in Belgium by user category, 2022

The study on cyclist accidents focused on Belgium, particularly on the effect of bicycle commuting on urban hierarchies and commuting distance. The results showed that urbanized settings, such as city centers with higher land-use intensity, were encouraged by shorter commuting distances. Conversely, the low-density locations experience longer commute times, which results in higher dependency on motorized transport, especially private cars. Unsurprisingly, higher cycle use is seen in regional towns as opposed to the bigger cities. Large cities, of course, have other deterrents to cycling, like high traffic volumes or the risk of bicycle theft. A new breakdown of communes shows sharply lower cyclist casualty rates in communes where more people cycle to work, particularly in Flanders with its pro-cycling policies, flat terrain and high population density and a strong cycling culture. Cycling that is safe and comfortable foster a positive feedback loop in which increased safety leads to greater cycling, as observed in the Netherlands (Vandenbulcke et al., 2009).

First, Vanparijs et al (2016) aimed to inform science-based safety policies by studying the causes and characteristics of bicycle crashes among adolescents aged 14–18 in Flanders (Belgium). Schools and insurance companies were surveyed using self-reported questionnaires from November 2013 to June 2015. The researchers analyzed 86 school-reported crashes and 78 insurance-reported crashes. Cyclist distraction and third-party failures to look out for cyclists crossing paths were each approximately a third of the reasons (29% each), while poorly maintained infrastructure made up 21%. Independent thereof, crashes that were reported to insurance companies took longer to recover from combined with more medical treatment and caused considerable time away from work (57% had missed at least one day). Only one-fifth of the crashes reported to insurance were in the police database, by comparison. The vast majority of crashes resulted from driver action (79%), with cars involved in 42% of them, but 31% were single-bicycle incidents. We recommend a mix of information, education, and environmental changes to mitigate the consequences of crashes.

2.4. Gender and age

Cycling simulator studies in Belgium have helped shine a light on how gender and age affect the way people cycle and perceive safety. One interesting pattern that's come up is that male cyclists tend to take more risks during simulations; they are more likely to break traffic rules or get involved in incidents. On the other hand, female cyclists generally ride more cautiously and make fewer mistakes (Ali & Ompte, 2023). Even more telling is that women often report feeling less safe in shared bike lanes and prefer cycling in protected, clearly marked paths. That speaks volumes about how urban design can encourage or discourage certain groups from cycling (Sakshaug et al., 2024).

Research has shown time and again that men tend to cycle more often than women (Garrard et al., 2012). There are a lot of interconnected reasons behind this gender gap in cycling. For one, studies suggest that men usually report facing fewer obstacles when it comes to cycling and tend to have a more positive attitude towards it than women (Akar, 2013). On the other hand, women often prefer safer cycling environments, like streets with slower traffic and more separation from cars. They are also more likely to see cycling as riskier than men (Prati, 2019). Understanding these differences and their reasons is important to encourage more people, especially women, to take up cycling worldwide (Munro, 2011). By focusing research on the experiences of cyclists, we can get valuable insights into how cycling behavior varies between genders (Heesch et al., 2012).

Age impacts cycling; older people, especially those over 50 years old, tend to avoid risky behaviour, and they may also face physical challenges, such as slower reaction times (Loomans et al., 2020). On the other hand, younger cyclists in their 20s might be more physically agile but do not always spot hazards as quickly or consistently. Their behavior in simulations showed differences in how they pay attention to traffic situations (Ali & Ompte, 2023).

All of these points point to something important: cycling infrastructure and safety programs need to take real people into account, not just the average cyclist, but riders of different ages, backgrounds, and comfort levels. More protected bike lanes, better signage, and tailored education can make cycling safer and more accessible.

2.5. The importance of using a cycling simulator

A simulator is designed to facilitate the simulation of a real-life situation and model a virtual version, often for instruction or experimentation in a laboratory environment (Ansariyar et al., 2022). Bicycle simulators (BS) are being used for various applications. Their use can be found in rehabilitation, sports, traffic safety research, and the study of bicycle dynamics. Each field has different design requirements for the simulators and their associated virtual environments. Using bicycle simulators in traffic safety research is based on evaluating how people experience different infrastructure layouts or react to specific traffic situations (Sporrel et al., 2023).

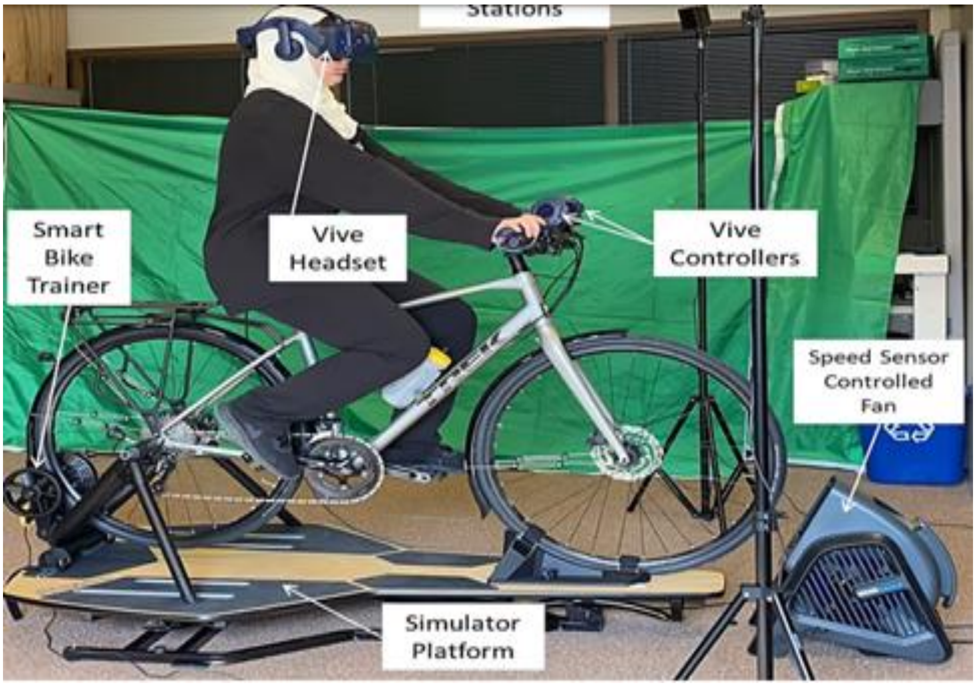

Figure 7:Virtual Reality (VR) Cycling Simulator Setup

An investigation in Japan developed a cycling simulator to help people ride safely. Subjects first received instruction on cycling rules and experienced scenarios of near misses at intersections, sidewalks and roadways through an interactive VR program. Following this, participants were probed for their impressions of each event and how that experience compared to ordinary cycling. The results revealed that after the improvements to the braking system, an experimental study was done, which showed that at-fault behaviour can be replicated by rule-qualified cyclists with the combination of a safety education program and a cycling simulator (Suzuki et al., 2018).

2.6. Challenges with the cycling simulator

Although there have been many papers on a wide range of riding simulators, bike simulator design remains one of the least investigated among human-powered, two-wheeled simulators. Of these challenges, developing a bicycle simulator is particularly challenging because the nature of the process (control of the human rider and control of an inherently unstable dynamic system (the bike) with a substantial actuator lag time). The real-time human pusher and pedaler simulation in virtual environments is a difficult challenge of recent introduction (Wohn et al., 2001).

According to the research conducted by Shoman & Imine, 2021, improving the dynamics of the bicycle model and simulating the effects of road geometry and surface characteristics such as radius of curvature, road adhesion, and unevenness of road profile shows that the impact of these characteristics on user behavior to improve the safety and stability of bicycles, particularly in bad weather conditions, has not been considered. Estimation of the vertical displacement and side slip angle has yet to be presented.

The evaluation and preference of routes are influenced by the degree of separation, traffic volume, and the type of road user the cyclists may need to interact with (Berghoefer & Vollrath, 2023). Cycling in a simulator differs from cycling in the real world. The steering and braking behavior of the simulator is different from that of real bicycles and needs to be practiced (Berghoefer & Vollrath, 2023).

VR sickness, simulator sickness, or cybersickness occurs when the signals your brain receives from VR cause a conflict with its senses, creating an uncomfortable feeling of nausea. Weech et al. (2019) argue that presence and cybersickness have a common origin, and the two have an inverse relationship.

Cybersickness (CS) denotes an ensemble of discomfort and queasiness symptoms induced by virtual reality (VR). It is usually classified as visually induced motion sickness (VIMS) and has different names depending on the triggering video display technology. CS is closely related to, but distinct from Continue Reading The studies of Kryspin-Exner et al. (2004) showed distinct symptom clusters under CS and simulator sickness (SS), yet the main difference between both is related to the symptomatology: Symptoms in CS mostly present as disorientation; whereas for SS symptoms predominantly represent oculomotor discomfort like eye strain and visual fatigue (Stanneyet al., 1997). Many people feel the symptoms of CS while in VR, but some do not seem to feel them at all.

2.7. Cycling training

Cycle training usually sets out to convey the skills and knowledge required to cycle in different road environments. According to Sung et al. (2005) For assessment of the training system's effectiveness, a Combined virtual reality technology with fixed exercise bicycle were used by Lajoie and colleagues on twenty normal healthy adults as test subjects to investigate the effect on equilibrium sensory control of varying the parameters. Measurements and analysis of deviations in path, cycling time, cycling velocity, center of pressure (CoP), etc., were also reviewed quantitatively; the advantages of virtual feedback information for weight shift effectiveness on balance training were examined. The results of the study demonstrate enhanced control over several cycling parameters, including balance, weight shift and global cycling abilities (i.e. cycling speed). Consequently, new training system using an exercise bike and a virtual reality system can be useful for enhancing equilibrium sense.

A bicycle simulator is used in traffic safety research, where BS examines how people experience different infrastructure layouts or react to specific traffic situations (Bastiaan et al., 2023). In on-road studies, participants interact with traffic, giving the most realistic description of a cyclist’s behavior. There are serious ethical concerns about testing behavior in field experiments, especially since testing critical situations increases the risk of injury to the participants. According to W. Wang et al., (2016), the introduction of virtual reality technologies to improve the safety of bicycle riders a user wears a head-mounted display and answers questions about his/her bicycle riding manners at each decision point in routes, and the study concluded that training systems using virtual reality technologies are useful for children unfamiliar with bicycles.

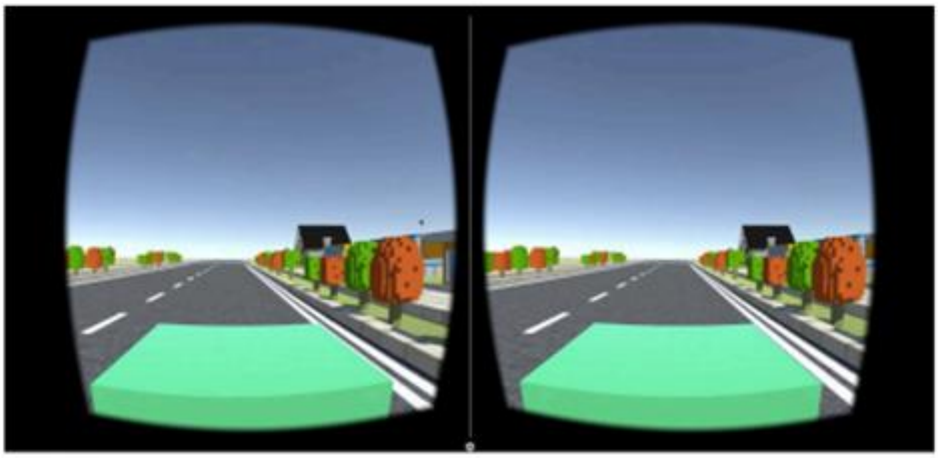

Figure 8:A scene from the scenario, users is riding along a road. The bicyclist and the bicycle handles are represented as a green cube (Wang et al., 2016).

The training even allows the users to participate in traffic accidents without putting them in harm since it makes use of virtual reality (VR) technology as part of their bicycle-simulated training; the type of this accident scenario is mentioned by Tsuboi et al., 2018, being avoidable and unavoidable. Avoidable accident scenarios simulate accidents that can be avoided if the rider is vigilant and follows riding best practices to remind them of the need for vigilance and safety precautions.

In contrast, the inevitable accident examples show collisions that still happen even when riders are doing their part, highlighting some of the dangers of riding in traffic and why we always need to pay attention. It addresses this by offering comprehensive feedback using the user's virtual riding data after a session or crash and from the dashboard and diagnostic system components. This feedback ranges from speed and distance to other vehicles and pedestrians, whether he is running any traffic signals, if he took the right road paths, etc. The feedback is a lot more complete and gives the extension user an idea about the safety they are riding with and how good their traffic manners are.

It also does not provide real-time alerts while training, like in the real world, where you often don't get immediate feedback. However, it also develops all alerts and indicates all infringements at the end of the session, which means that learning individuals can locate and assess their behavior in future rides (Fallon & Hemi, 2016).

2.7.1. Workshop training

Rigal, (2022) explores subcultures in a qualitative study based on participant observation and interviews within French bike workshops, which are components of the cycling subculture. Subcultures can be understood as limited social subsystems that exist within the society, where a common set of beliefs, values, and behavioral norms is valid and which often seek to resist the main streams of that society.The focus of the research concerns two bike workshops, one of which is Small Bike, established in Grenoble in 1995, and a more recent City Bike workshop located in the Greater Geneva region. Although Small Bike is based on radical innovation and is operated by volunteers, City Bicycle has a closer relationship with the local governments. Both workshops are located in lower-middle class, multi-ethnic areas and provide such activities to the members as mass bicycle rides and self-service bicycle repair. These workshops foster an environment where cyclists can not only have their bicycles serviced, but also pick up some much necessary bike repair, and get acquainted with fellow cyclists helping to promote cycling as an alternative to cars.Forthcoming analyses of the data collected from 40 interviews and participant observation reveal the ways in which bike workshops act to change the habits of the members. Workshop members repair their own bikes more often, do not use cars as much if at all, and lead greener lifestyles. Furthermore, workshops offer a means of independence as they teach members how to repair bicycles, as opposed to cars which require expensive repairs by professionals, The findings illustrate how changes in habit occur within a domain of cycling subculture, causally or deductively influencing development of the bond between a person and a bicycle. The hanging sentence gives insights into the possible uses of Berger and Luckmann's theory in relation to mobility practices.

2.7.2. Road training

Van Hoef et al., 2022, conducted research with the aim to analyze the influence of short term bicycle training on adolescents' cycling skills and also to analyze the interrelationship between distance from home to school, mode of transport on the pupils, use of the bicycle and the pupils' cycling skills. The sample consisted of 77 adolescents aged on average in the range 16- to 20-year-olds with 48 participants in the intervention group and 29 in the control group. Standing tests were performed for every group and at baseline and then for each group two weeks later with the experimental group being trained two hours a week with the baseline taken a week before. It was noted that the increase of cycling skills of pupils who were bicycle trained was significantly higher than that of control pupils with regard to control tasks such as riding over the wooden plank and rode a controlled step on the cyclist. Correlational variables in the study included cycling skills, bicycle usage, circumstances of how pupils got to their school or destination, the only variable which was not held to be associated with the distance involved was the geography of school buildings. In summary, the participants gained cycling skill enhancements within a short period of receiving bicycle training.

2.7.3. Computer training

Virtual online training has become a major fitness trend in 2021, with rapid growth in the cycling community through virtual training and competition. However, critical evaluation of these platforms remains limited. The strengths of virtual training include immersive virtual worlds, innovative drafting mechanics, and versatile training options. Weaknesses involve concerns about data accuracy and unreliable power-speed algorithms. Opportunities lie in expanding partnerships with major cycling events, brands, and sponsors, as well as enhancing user experience through video capture and "e-coaching." However, threats such as cheating in competitions and limited acceptance by a broader audience pose challenges to its growth (McIlroy et al., 2021).

The Connected Bike project combines multiple hardware and software technologies to provide modern training for bicycle lovers. This system provides trainers with the ability to evaluate parameters such as speed, cadence, and power produced by a cyclist through an exposed Web Application. It also provides a GPS coordinate system for watching the current location of the cyclist. Collecting hardware, which contains the sensors and their transmission, is incorporated in the hardware. Management of the data is performed on the software side. The system consists of a Back end and an MQTT Broker responsible for transmitting data in real time and a Front-End that provides two-way communication between trainers and cyclists. Furthermore, cyclists have an Android app that enables them to decide when and how the ride is supervised off-site (Catargiu et al., 2020).

2.7.4. Video game training

As shown by statistics, one of the more serious risk factors in road traffic collisions is cyclist inattention, especially as children are more likely to be impaired than adults, and their hazard recognition ability is far lower than that of an adult. This study aimed to address this issue by encouraging concentration during a particular video-based intervention on the content to incorporate the use of virtual reality scenarios in video games to enhance situational awareness while cycling on the road. A total of thirty-three 10-12-year-old children were assigned to either control or intervention groups after being exposed to UK cycle training. Cyclists in the intervention group participated in an activity where they watched first-person footage of cyclists while exercising on a bike. Both groups were then also evaluated for their bicycle handling performance by professional instructors in urban areas of Britain. Participants in the experimental group scored higher on performance metrics such as observation of the road environment, information exchange, riding position, and comprehension of roadway hierarchy. Still, no changes were reported in the subscale of cycling self-efficacy or situational awareness. Based on the results, its effectiveness can be extended to video game scenarios to simulate road situations enhance cycling safety, and even complement normal cycling training regimens. With the increasing shift towards cycling as a means of transport in the UK, virtual training programs could be a great way of ensuring young cyclists are ready for the cognitive demands of riding. More research is necessary to design reliable tests of situation awareness that can be used to forecast on-road cycling performance (Bishop et al., 2022).

2.8. Evaluation of the cycling simulator

2.8.1. General Overview

Experimental design is a scientific research method where one or more independent variables are manipulated to observe their effect on dependent variables. The researcher controls all factors influencing the outcome, aiming to predict or determine what may occur. In statistics, experimental design refers to a controlled experiment where variation is present or absent, conducted under the researcher's full (Zubair, 2023).

The Experimental Group undergoes treatment, program, or intervention of interest. The Control Group set of diverse circumstances is placed on the individuals chosen for the experiment during the manipulation procedure. The collection of different circumstances is known as the independent, experimental, or treatment variables. Designs in which one or more experimental groups are exposed to a treatment or intervention and then compared to one or more control groups who did not receive the treatment. Brief notes on such designs' internal and external validity are first necessary. Internal validity is the degree to which the experimental treatment makes a difference in (or causes change in) the specific experimental settings. External validity is the degree to which the treatment effect can be generalized across populations, settings, treatment variables, and measurement instruments (Dimitrov & Rumrill, 2003).

According to O'Hern et al. (2017), they Conducted a study to assess the behavioral validity of a newly developed bicycle simulator by comparing participants' cycling performance on the simulator with their performance on road. The study used a within-subjects design, involving 26 participants aged 18 to 35 years.The study found strong evidence of validity for spatial positioning measures, such as average lane position, lane position deviation, and passing distance from parked cars. Relative validity was also established for cyclists' average speed and speed reduction when approaching intersections.

Jobson et al., 2012 conducted a study on mobile cycle ergometers, such as SRM™ and PowerTap™, which allow the measurement of the power output of cyclists during training and during competition, but as it was found, the average power can be considered as a poor value of the physiological strain due to the power output variability. One option is to estimate "the normalized power" using an exponentially weighted average which is more reflective of a cyclist's load. Systems theory and application of the impulse-response models have been used to explain the load and performance relationship; however, these models are characterized by a high number of performance tests and may not account for the biology adaption's nonlinear response. ANN provides one way of overcoming this but has the downside of requiring large data sets. Other mathematical modelling techniques like Performance-Potential-Metamodel (PerPot), mixed linear modelling, cluster analysis, and chaos theory show great promise but need more work before they become viable alternatives. Although these may not be able to model the link between training and performance directly, they will certainly help in modelling the complex relationship of physiology and training.

2.8.2. Process evaluation and effect evaluation

Process Evaluation allows an organization to examine how it develops its structures and its programs in order to attain the outcomes everyone wants it to achieve. In other words, process evaluation documents the process of a program's implementation. Process evaluations help stakeholders see how a program's outcomes or impacts are (or will be) achieved. The focus of a process evaluation is on the types and quantities of services delivered, the beneficiaries of those services, the resources used to deliver the services, the practical problems encountered, and the ways such problems were resolved (Roger & Boothroyd, 2018).

Effect Evaluation assesses the effectiveness of a program in producing change. Outcome evaluations (or impact evaluations) focus on the questions about what happened to program participants and how much of a difference the program made for them. Impact or outcome evaluations are undertaken when one wants to assess whether and how well the objectives of a program were met (Roger & Boothroyd, 2018). An example of effect evaluation is a 65% reduction in the number of jail days among program participants while in the program compared to one year prior.

3. Research methodology

3.1. Bicycle simulator scenarios

The cycling simulator at the Transportation Research Institute (IMOB), Hasselt University, is a sophisticated setup designed to simulate real-world cycling environments for research and training purposes. The simulator typically consists of a stationary bicycle positioned in front of a large three-projection screen that displays dynamic visual scenarios and a control system. This immersive environment simulates a wide variety of road and traffic conditions, allowing the study of cyclists' behaviour and interactions with traffic in a controlled setting. The simulator provided scenarios designed to test cyclists' responses to different situations. Simulating road characteristics such as narrow streets and cycle paths with different markings and simulating unexpected events like simulated occurrences such as suddenly pulling out of driveways or pedestrians crossing the street unexpectedly. The simulator allowed for variable speeds, replicating the real-world scenario where cyclists adjusted their speed based on road conditions and traffic. This flexibility enabled participants to experience a more realistic cycling experience, where they must determine when to slow down, speed up, or change lanes.

The bicycle simulator is a bicycle on a stationary platform. All actions that the cyclist makes are joined with the bicycle and reflected to the wall. Thus, with the help of a platform and projector, the participants don't move, but at the same time/they can pedal and see the road move. Participants can pedal on a bicycle simulator while observing a projected road environment. The displayed environment moves in synch with their pedaling, while physically, no movement is required from the participants. This allows for total immersion in the simulation. The bicycle is real, and a smart trainer is affixed to the back wheel. The smart trainer allows for realistic sim pedaling, shifts, and braking with respect to rolling motion and speed. Steering is done through handlebars connected to a motor, and the STSIM Drive3 program powers the virtual environment. Displays for the simulation consist of three 43" monitors, totaling 5760x1080 pixels across all three. The combined field of view of the displays is 135 degrees, each running at approximately 30 frames per second. Each frame of the simulation is recorded and accompanied by ambient sound effects from speakers on the central monitor to increase realism.

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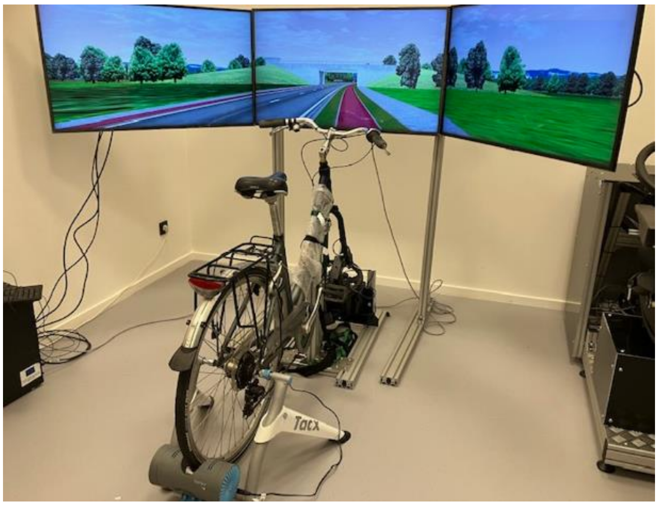

Figure 9: Cycling simulator components at IMOB

Like in the real world, this virtual traffic training program integrates a realistic driving experience within Belgium’s infrastructure and features a dedicated bike lane (2 in Figure 10) and car lanes (1 in Figure 10). The simulation also has its share of “realistic” cycling difficulties, including flashing signals, surprise cars, poor visibility, pedestrian movement, and disorienting road signs. Participants can track their speed and distance with the digital dashboard as shown with green numbers in the following figure; the interactive scenario goes beyond being a mere engaging activity – it offers a valuable opportunity for faculty to evaluate a grown adult's ability to cope with road threats and challenges.

Figure 10: Simulated environment

In total, the distance is 1599 m and the scenario's duration depends on the participants' cycling speed.

1. Respecting the Shared path for pedestrians and cyclists sign: The cyclists should stay on the left

Figure 11Cyclist and pedestrian paths

2. Respecting the yellow lane for cyclists: The cyclist should use the yellow lane

Figure 12: Yellow Lane

3. Overtaking a parked vehicle in a yellow lane: To overtake a parked vehicle, use a roadway or use a sidewalk if you are younger than 10 years, and always make sure the vehicle does not tend to depart

Figure 13: Overtake a parked vehicle

4. Give priority to the parked cars on the side of the road: Be careful of the parked cars. Even if you have the right of way, they can suddenly depart.

Figure 14: A parked vehicle on the side of the road

5. Designated cycle path end: Cycling on the sidewalk is allowed only for people younger than 10 years old people

Figure 15: The designated cycle path end

6. Give priority to the car from the left in Bicycle Street:On Bicycle Street, the car from the right has a right of way

Figure 16: Priority to the car from the right

7.Give Priority to Pedestrians: Pedestrians waiting at crosswalks have the right-of-way of way on bicycle street

Figure 17: Give priority to the pedestrians

8.Give priority to the bus stop: The cyclist should always allow the people exiting the bus to do this in a safer manner

Figure 18: The people get off and get on the bus at the bus stop

9. Priority to the cyclist's signs: The Forbidden sign with the minor additional signs indicates you are allowed to go straight

Figure 19:A cyclist's sign allows the cyclist to go straight

10. Priority to the cyclist:In the intersection with a sharp triangle sign drawn on the road from the right, the cyclist has the right of way

Figure 20: Priority to the cyclist

11. Stop sign: Stopping is mandatory

Figure 21: Stop signs

12: Sign allowing cyclists to go straight even with red light:Only when the sign is present cyclist can go straight during a red light

Figure 22: Give priority to the cyclist sign

13.Cyclist sorting area

Figure 23: Sorting area

There are two categories of hazards: open and hidden. Open dangers (in the context of cycling) include complete stops at stop signs and obeying the change of traffic signals (Figure 14 and Figure 22). The hidden dangers are a car coming from the right side and the people getting off the bus (see Figures 16 and 18)

3.2. Participants

The participants were the student community at Hasselt University, without Belgian nationality. A convenience sample of participants was recruited through university direct emails sent to students, direct messaging, and social media (WhatsApp and Facebook).

They filled out a registration survey including their availability for two tests, a pretest, and a post-test, for the interval of one week between the two tests. After confirmation of participation, participants were asked to come to the university at IMOB. For the arrival at the cycling simulator room on the agreed time and day, participants filled out the pretest questionnaire developed on the Qualtrics website, which was aimed at figuring out background information, assessing cycling behaviors using the cycling behavior questionnaire (CBQ), and evaluating traffic signs knowledge. The process took around 10 minutes. Before beginning the simulator, participants were given information about the experiment and the functionality of the equipment.

For this study, participants are randomly assigned to a control group (CG) and an experimental group (EG). The CG pretest consists of an online pretest questionnaire (with informed consent), followed by a non-interactive simulator ride. One week later, they did a post-test, which is the same as pre, but with the situations in a different order, and an online post-test questionnaire similar to the pretest was completed with no feedback. The EG follows a similar pre-test procedure, starting with an online pretest questionnaire and an initial simulator ride without feedback. Immediately afterward, they receive a training session that consists of a second simulator ride with scenario-based Reading & listening feedback and an online training questionnaire about the training experience. The post-test for the EG group mirrors the CG group, and it is done one week later and consists of a simulator ride and an online post-test questionnaire. It is important to note that in training, the feedback is based on situational scenarios. Participants can view alternative feedback versions when engaging with the scenario, but in the movie format, participants view only one version of the feedback per situation, with more detailed feedback from the researcher.

3.3. Questionnaire

Four types of questionnaires, Registration, Pre-test, Additional, and Post-test, were used in the study to allow systematic gathering of relevant information and evaluation of participants' experiences and results accurately. The registration questionnaire was the initial instrument, with no testing to be initiated. Its purpose was to gather essential participant details such as age, sex, experience in cycling, and availability so that the study could begin with full awareness of the participant group. Following registration, participants completed the Pre-test questionnaire, which would be used as a baseline of comparison in the future. The Pre-test questionnaire had a participant ID Number, pre-assigned by the researchers, to maintain anonymity while allowing tracing during all study phases. The pre-test was an indication of participants' previous attitudes, knowledge, and behavior regarding cycling. Significantly, it also included the Cycling Behaviour Questionnaire (CBQ), a tested-in-the-field instrument specifically designed to directly assess primary aspects of cycling behavior such as frequency, confidence, compliance with rules, and subjective risk perceptions. With the CBQ at this stage, researchers were able to establish a baseline of behavior prior to any intervention. The Additional questionnaire was administered immediately after the Experimental Group (EG) completed their training session. The tool was created to capture participants' unfiltered responses and feedback regarding the Experimental Group's training topic, format, and delivery. It attempted to capture perceived usefulness, ease of understanding, and relevance of the training content when it was fresh in participants' minds. Just like the earlier tools, this questionnaire began with the participant's ID number to ensure consistent tracing of data. Lastly, all the participants completed the Post-test questionnaire one week after the pre-test.

The measure nearly exactly mirrored the pre-test in terms of design and content in order to allow for effective comparison over time, particularly as it concerned changes in behavior, attitude, and knowledge. Significantly, it also re-administered the Cycling Behaviour Questionnaire (CBQ). By comparing pre- and post-intervention CBQ responses, the study was able to establish quantifiable changes in cycling behavior among participants.

As informed consent had already been provided in the pre-test process, there was no duplication in the post-test. The final questionnaire had only a few minimal demographic confirmation questions to check participant identity and ensure data consistency.

3.4. Data analysis

Data analysis was performed on the questionnaire and the data from the simulator. A unique identification number was given for every participant in the study, which was uniform in both parts. The questionnaire and the simulator data compiled in a single Excel file made the analysis effortless and mistake-free which was subsequently saved in SPSS (.sav) format. Participants responded to the questionnaire online through the Qualtrics platform, which contained preliminary demographic inquiries capturing gender, age, incident history, and instances of being pulled over by law enforcement in the pretest questionnaire, and the questions to test traffic knowledge were the same within pre- and post-test. Data from the questionnaire was collected to obtain the participants' demographic details, driving behavior, and attitude data concerning traffic safety. Responses from the questionnaire and simulator were evaluated through IBM SPSS Statistics 29.0.1.0 (171). Means, standard deviations, and correlation coefficients were calculated for all descriptive metrics to determine differences and relationships between multiple factors. Main variables were measured using T-tests and repeated ANOVA with a confidence interval of 95%. Repeated measures ANOVA was performed to evaluate time as a factor for both simulator performance and questionnaire responses. This enabled the evaluation of the change within-subject effects (the change from pre- to post-test), then between-subject effects (the difference between CG and EG), and any interaction effects that may suggest different progression patterns over time across groups. Significant effects were determined using p values of less than 0.05. The data was exported to SPSS for detailed analysis and examination of how the various collected variables relate.

The dataset noted outliers for participants with IDs 12 for CG, 13 for EG, 27 for EG, and 28 for CG. These respondents and their responses in the simulator were unusual since, for example, pretest vs post-test simulator scenarios had a response with a z-score bigger than +3 or smaller than -3. As explained earlier, z-score measures the distance of a given value from the mean in standard deviations; in this case, a score above +3 would mean it was notably higher than average, and anything below -3 is considerably lower. In most datasets, values outside the ±3 range are statistically rare, signifying they stand the chance of being outliers. These outliers create interesting observations; for example, certain participants do not understand what they are responding to or behave differently than expected, and two did not show up for the post-test. With the data obtained from the participants, it was decided to remove the data from the four identified participants as outliers. Justifying this decision would lead to the final sample of 31 participants, with 16 participants in the EG and 15 in the CG, whose data were used for further statistical analysis

4. Results

4.1. Background information

In total, data from 31 participants were taken for further analysis after removing outliers. The average age of participants is 29.87 years, ranging from 23 to 38 years with a standard deviation of 3.13 years.

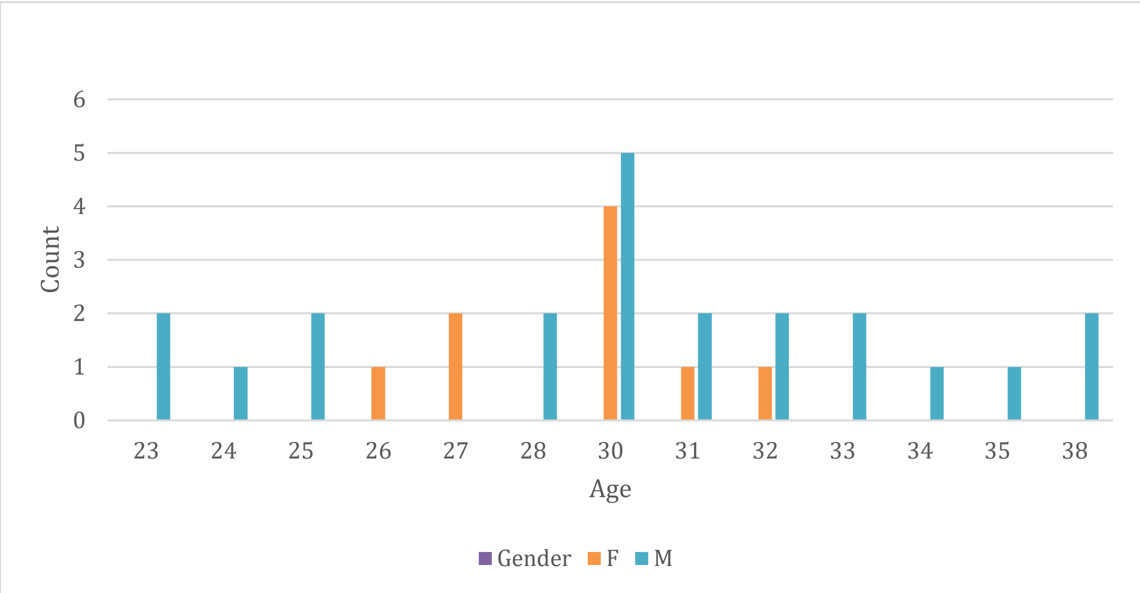

Figure 24: Gender distribution

Figure 24 shows that the gender distribution was 21 males, 71%, and 9 females, 29%. The average age for males was 30.14 years with a standard deviation of 4.30 years, and for females it was 29.22 years with a standard deviation of 2.05 years.

The variable length time reflects how long the participants lived in Belgium, with different durations shared by 31 participants. The most common response was 1.5 years, chosen by 35.5% of them. This was followed by half of the year, equivalent to 22.6%, and 3 years of 16.1% of participants. These three values comprised more than 74% of all responses. Less frequent answers included 1, 2, 2.5, 5, and 6 years. Details are shown in Figure 25.

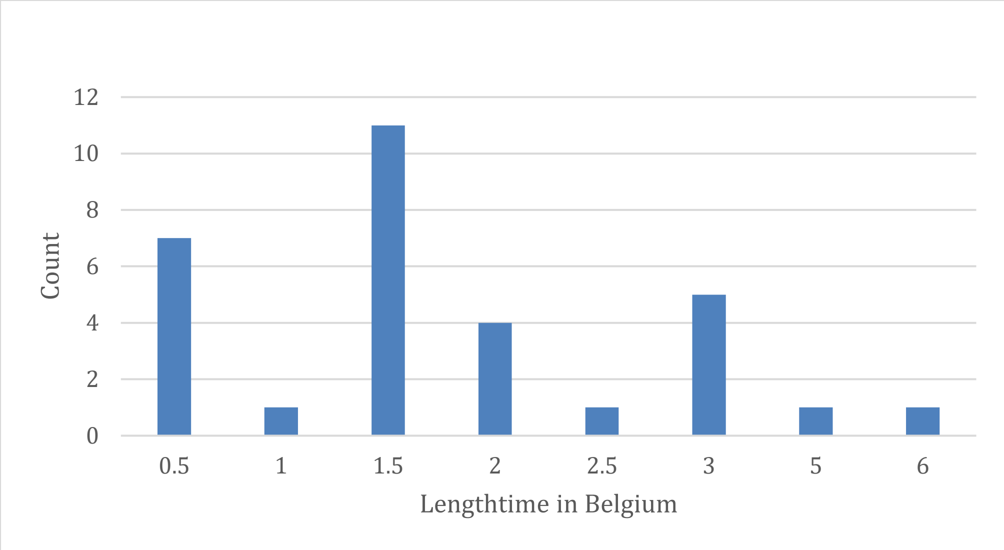

Figure 25: Length of time for participants in Belgium

The variable Nationality captures the countries of origin for all 31 participants based on the figure 26. Rwanda was the most common nationality, representing 32.3% of the entire group. Uganda came next with 9.7%. Several other countries, Cameroon, Ethiopia, Ghana, Iran, Nigeria, the Philippines, and Vietnam, accounted for 6.5% of participants. A few nationalities, such as Kenya, Pakistan, Tanzania, and the USA, were mentioned just once, making up 3.2% each. The data reflects diverse backgrounds, with Rwanda being the most represented. It is also worth noting that no responses were missing, as the valid and total percentages are the same.

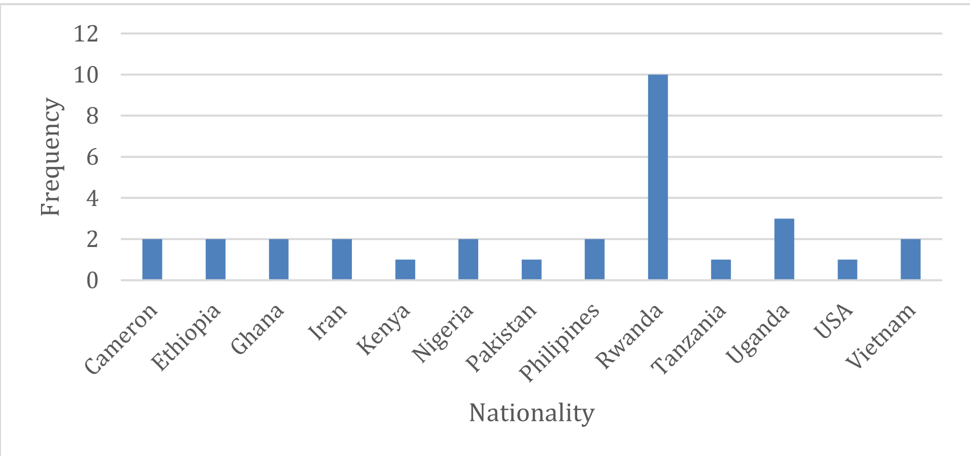

Figure 26: Nationality of participants

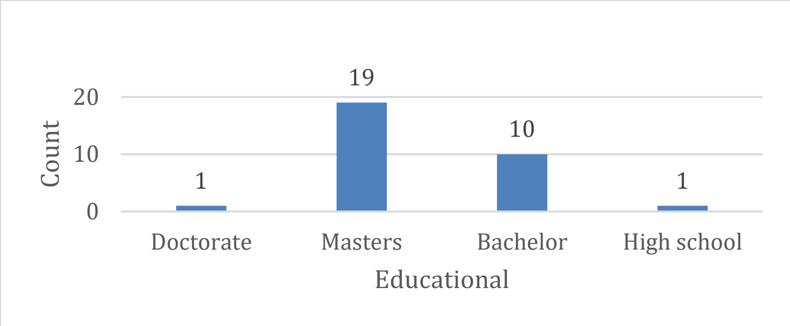

Figure 27: Education background of participants

The group of participants in this study seems to be quite well educated as stated in figure 27. Of the 19 people, most have earned a master's degree, showing a strong representation of postgraduate education. Ten others hold bachelor's degrees, indicating a solid foundation of higher education. One participant with a PhD, the group's highest academic level, and one who completed their education with a High School Diploma. Overall, most participants come from an academically advanced background, which could shape how they think about and respond to the topics explored in the study.

4.2. Means of transport used

They were split into two experimental conditions: Control Group and Experimental Group . Within the CG participants, all the men (n = 10) and all the women (n = 5) cycled as their principal mode of transport, therefore representing a 100% cycling rate within both genders. Walking was also common in the CG, with 20% of men (2 out of 10) and 40% of women (2 out of 5) reporting using their feet frequently. One man (10%) in this group reported using a car, and none used scooters.

In contrast, the EG participants showed somewhat divergent trends. In males (n = 12), 75% (9 participants) cycled, 25% (3 participants) walked, and 16.7% (2 participants) scootered an activity not mentioned by any female participant in either control condition. EG females (n = 4) had a 75% cycling rate, which was slightly lower than the cycling rate in CG females. Half the EG women (2 participants) named walking as a common mode of transport, and none named cars or scooters.

Overall, cycling was the most common mode of transport among both groups and sexes and showed an incrementally increasing rate in the control group. The use of scooters was confined to males in the experiment group, with car use isolated, reported by one male subject across the sample. These findings highlight a strong preference for active transportation modes, most notably cycling, and considerable secondary mode differences by gender and group for walking and scooter travel.

4.3. Cycling in Belgium

Participants in the study shared that they cycle in Belgium, and their reasons reflect a nice mix of practicality and enjoyment. The most common reason was getting to school and work, with about 42% of them using their bikes as a daily mode of transport. It's clear that for many, cycling is a regular part of their routine. Some participants cycled for more than just commuting. Around 10% mentioned they ride their bikes for fitness, recreation, and commuting, a well-rounded use that blends health, leisure, and convenience. Another 10% said they cycle mainly for fitness or sport, showing that cycling is a key part of staying active for some. There are a few more varied reasons, like combining errands, recreation, commuting, or just cycling for fun. Out of 31 participants who were asked, 20 (64.5%) have a bike, and 5 (16.1%) do not have a bike. A few fewer (4 participants, or 12.9%) ride a bike on a permanent rental basis, and 2 individuals (6.5%) use bike-sharing. With regard to the kind of bicycle ridden, a vast majority of 27 respondents (87.1%) use a normal bike. Some indicated using electric bicycles, 3 participants, or 9.7%, while one person (3.2%) indicated the use of some other form. For safe practices, 13 participants,41.9%, indicated wearing a cycling helmet, while 18 (58.1%) did not, suggesting an area for improvement in promoting safer practices for cycling.

4.4. Traffic accidents

As reported in Figure 28, the study explored participants' past history of traffic crash involvement while cycling in Belgium as a measure of actual risk exposure and safety behavior. Out of the entire 31 participants, 21 (68%) reported that they never had any cycling accident, 7 participants (23%) reported being involved once in a bicycle accident, and 3 participants (10%) reported being involved twice in separate incidents. When broken down by group, the Control Group included 12 members with no accidents reported, 2 members who had one accident, and 1 member who had two accidents. Compared to the Experimental Group that had 9 members with no reports of accidents, 5 with one accident, and 2 who reported two accidents.

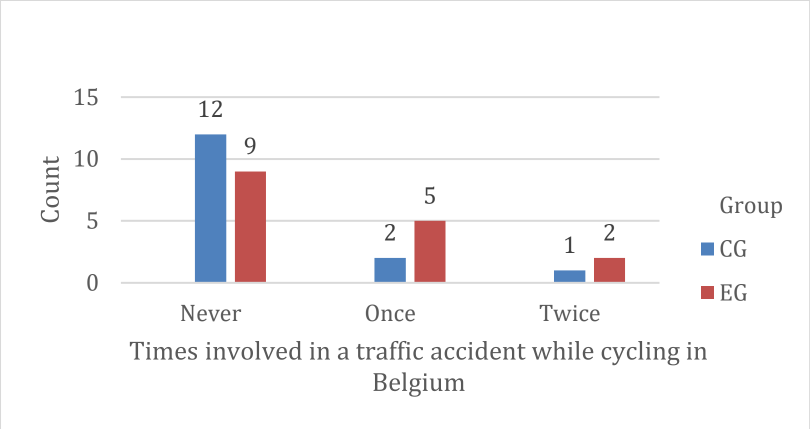

Figure 28: Time involved in accidents

Surprisingly, the EG had a slightly higher number of participants with a history of accidents in relation to cycling than the CG, as illustrated in Figure 28 above. It may be that EG participants were more avid or experienced cyclists or exposed to Belgian traffic conditions more regularly prior to the experiment. Regardless, performance on their traffic simulation improved, in particular after having been exposed to directed education, suggesting that accident history was not a determinant of their learning outcomes. On the other hand, it might have enhanced their vulnerability to safety training. The above discovery dictates the need for intervention that not only addresses theoretical knowledge but also interventional engagement on the everyday practical safety concerns of the cyclists in the field. Among the participants who reported being involved in a cycling accident, the most common issue, as illustrated in Figure 29, was a collision with another cyclist, mentioned by 4 respondents.

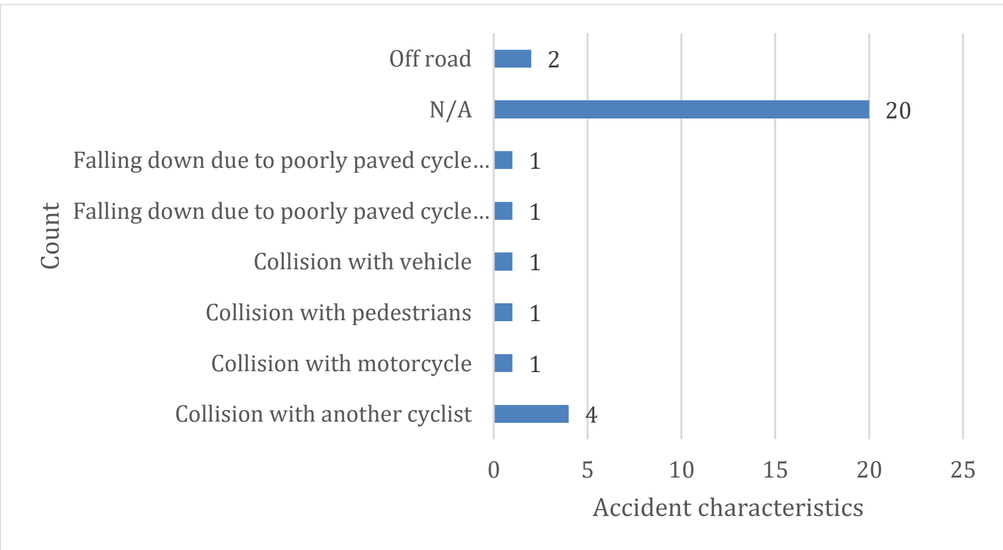

Figure 29: The characteristics of the accident occurred

4.5. Consequences of a cycling accident

Most participants (67.7%) left the question blank about the consequences of a cycling accident, likely because they had never been in an accident. In the control group (CG), only three members reported any experience with cycling accidents. Half (50%) reported damage to material, and 25% each reported serious injuries or indicated they had never had an accident. In comparison, the experimental group (EG) had more members reporting consequences, with six providing responses. The most reported consequence was minor injuries, which accounted for 66.7% of EG responses. One of the participants (16.7%) from the EG reported both minor injuries and damage to property, and one reported only damage to property. In this comparison, it is possible to conclude that more minor injuries were reported by participants in the EG, yet the CG reported a greater range of outcomes, including more severe events.

4.6. Traffic fines

Traffic fine history tells us of the real-life compliance behavior of cyclists and their knowledge of traffic regulations. Respondents in this study were asked if and how often they had ever been charged with a traffic fine. The results showed that 2 participants (13%) from the Control Group had been fined one or more traffic fines, but none of the Experimental Group had ever witnessed any such occurrence. Secondly, in responding to the frequency of events, one participant of CG answered that they had been fined several times, and the remaining 14 participants in the CG, and all 16 EG participants, answered that they had never been fined. This difference highlights a possible greater pre-study vulnerability to traffic offenses on behalf of the CG participants, who were not given targeted training on the study. Absence of traffic fines in the EG can be attributed to more conservative behavior or possibly less exposure to Belgian traffic systems at the time of data collection. However, these results further lend credit to the assumption that organized education, more specifically, simulator-based training, may be a preventive measure, with cyclists being provided with information and decision-making skills to prevent infractions.

4.7. Traffic Education

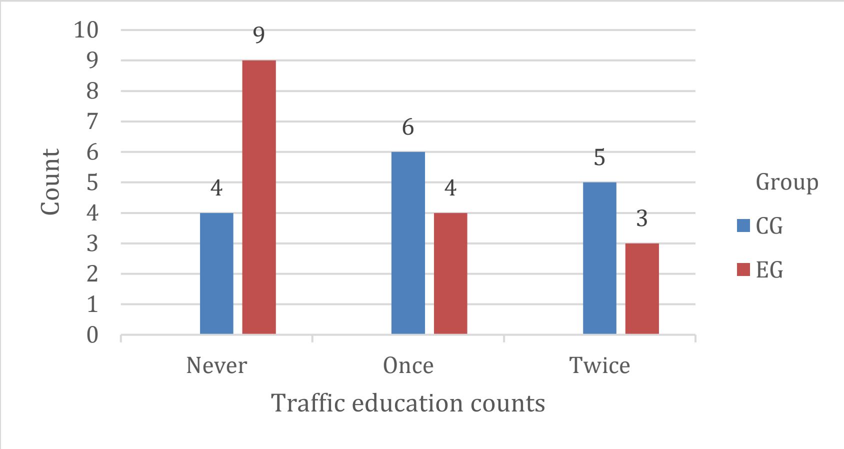

Figure 30: Traffic education counts

Figure 30 shows that CG, 11 out of 15 participants (approximately 67%) responded that they had prior traffic education in Belgium. In the EG, however, only 7 out of 16 participants (approximately 44%) ticked the same. This would mean that the CG began the study with a comparatively stronger baseline of formal traffic education. However, the essential difference between the two groups lies in the type of intervention each was provided during the study. While the CG completed both simulator sessions without targeted training, the EG was given an additional systematic education module through the simulator between their pre- and post-test.

For the subjects who had already received traffic education, the modes of delivery also varied by group. For the CG, training was equally divided: four participants received online education, another four received physical (face-to-face) sessions, and two received a combination format of the two modes. For the EG, three participants were provided with online instruction, three received physical sessions, and one received the combined format. This pattern indicates a reasonably even distribution across formats but also reveals that CG participants had somewhat higher exposure to different educational methods before the study.

4.8. Traffic signs

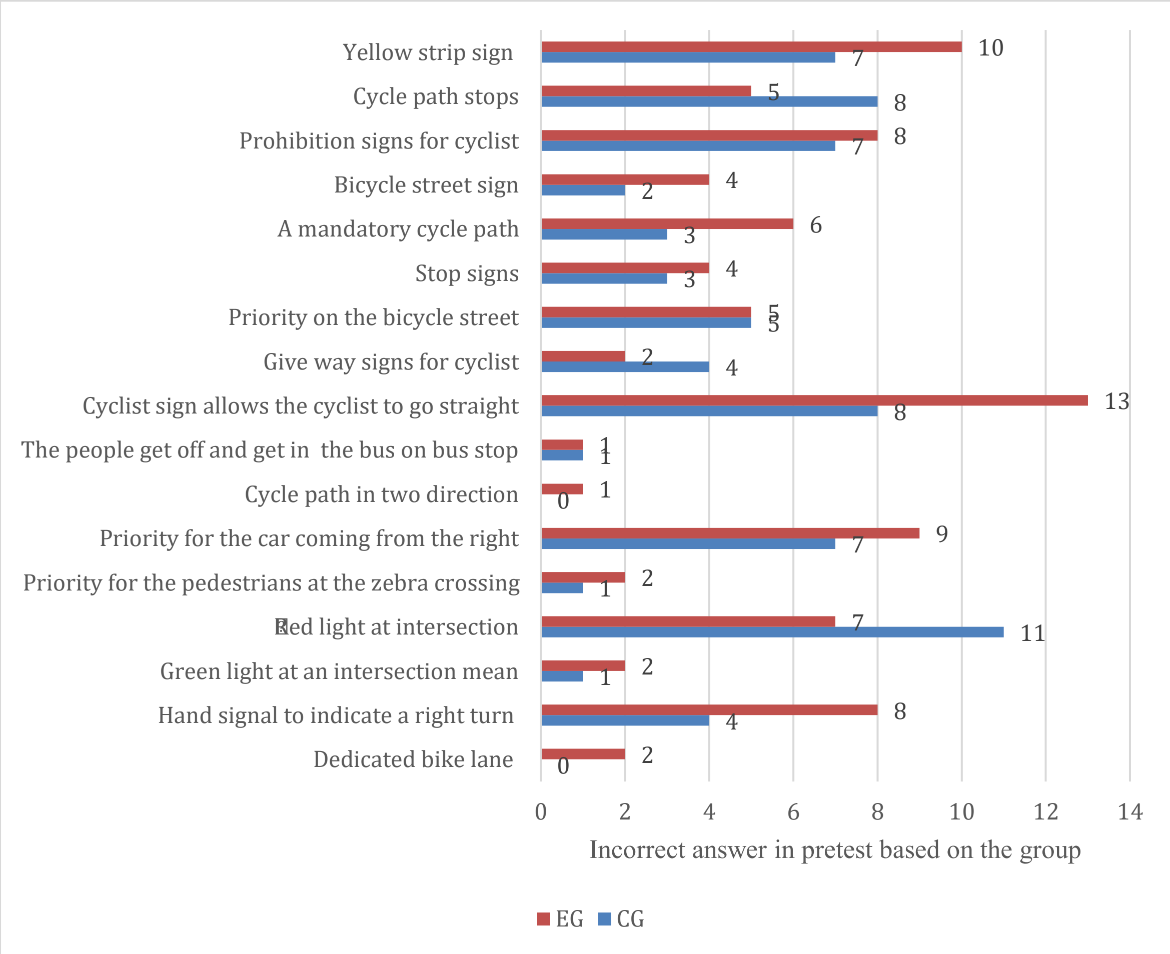

Figure 31: Incorrect answer in pretest based on the group

CG and EG understood some of the basic cycling rules but also got into trouble in a few trickier situations, as shown in Figure 31 above. For example, some in CG correctly answered what to do when there's a dedicated bike lane, while some people in EG missed that one. On questions like whether cyclists should give priority at a zebra crossing or what certain traffic signs mean, CG again had fewer mistakes. That said, there were a few questions that stumped both groups. One of the most confusing ones was whether cyclists can go straight at an intersection when the light is red. Eleven people from CG and seven from EG got it wrong. Another tough one was about right-of-way when a car comes from the right, something many cyclists aren't sure about. On that, CG had seven incorrect answers and EG had nine. Interestingly, EG did slightly better than CG on one question about interpreting road signs, but they also struggled more with the question about what a yellow strip on the road means. Ten people in EG missed it, compared to seven in CG.

4.9. Impact of traffic education on the experimental group

The response to the central evaluation questions shows that male and female subjects both had a good time, although response patterns differ in some distinct ways. There were four females and 12 males in the experimental group. From the response to the cycling simulator evaluation, both female and male participants had an overwhelmingly positive experience in general. However, there were some interesting differences in their evaluation of specific aspects of the program. In their overall experience, males gave a little higher rating with an average of 4.67 out of 5, while females rated it at 4.25. All participants in the experimental group were very consistent in their answers, showing overall agreement that the program was fun and well-structured. As for how well the education worked, women rated it better, with an average of 4.75 to 4.42 for men. That is, men had more fun, but women believed it was more effective in teaching them. The two groups were in accord that they did learn to be better cyclists, with an average of 2.5 on a 3-point scale between "Yes" and "Totally Yes."

Confidence levels had the greatest difference. Men were more confident in using what they had done in actual life, with a mean of 4.25 against 3.75 for women. Female responses had greater variation, which suggests that while some women were highly confident, others were less confident. This could be attributed to different cycling experiences prior to this course or differences in learning abilities. Last, on how likely they were to recommend the simulator, both groups strongly agreed with "very likely." Once more, however, males averaged a bit higher, 4.5 compared to 4.25. Women, as before, had more diverse responses here as well. All in all, while men were ever so little more enthusiastic for most questions, women found the program especially effective and reported enormous gains in skill and confidence. The reviews say that the simulator is wonderful for everyone and has slightly varying focuses depending on the group.

4.10. Simulator

Some patterns stand out in how the CG and EG groups performed across the scenario-based situations for the pretest simulator, as illustrated in Figure 32. On average, both groups showed difficulty with specific situations, particularly those involving practical road situations. For parallel car exiting, parking had the highest average number of incorrect responses, with 14 errors, CG making 13 mistakes, and EG slightly more, with 15. The standard deviation was 1.41, showing the errors were relatively evenly distributed across both groups.

One of the trickier situations for participants was about the cyclist's suggested lane. This was especially challenging for the experimental group, which had ten incorrect answers, compared to six in the control group. There was also more variation in how people answered, with a standard deviation of 2.83, suggesting that this rule wasn't understood. That said, not all the questions were confusing. Some were answered almost perfectly. For instance, regarding the rules around cycling lane stops, both groups got it entirely right, with zero wrong answers. This rule was well communicated and understood. Similarly, the situation about cars approaching had a relatively low error rate, with an average of just 4.5 incorrect answers. The standard deviation was only 0.71, meaning there wasn't much difference in how the control and experimental groups performed on this one. As for the shared pedestrian and cycling lanes, the experimental group actually did slightly better, with seven mistakes compared to nine in the control group. However, overall, the average number of mistakes across both groups was still around eight, with a modest standard deviation of 1.41.

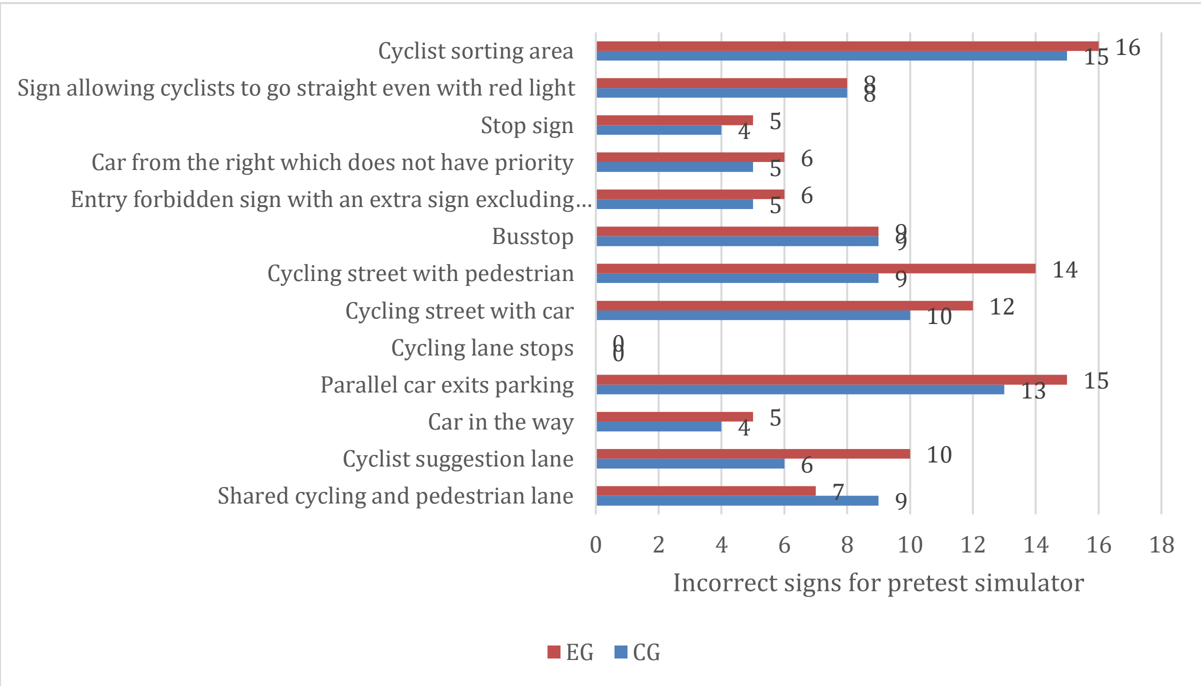

Figure 32: Incorrect traffic signs for the pretest simulator

4.11. Statistical test results

At the pretest phase for the questionnaire, both the EG and CG were comparable in terms of performance for most items. With the Independent Samples t-test results, there was one item with a statistically significant difference, though: the item measuring riding straight through a red light had a p-value of 0.050, with the EG performing higher than the CG (mean difference = +0.296), suggesting a possible difference in interpretation or conservatism. A second task, cyclist sign awareness, allowing going straight, was on the brink of significance ($p = 0.053$), with the CG performing better (mean difference = -0.279). In this instance, Levene's test identified strongly unequal variances ($p = 0.006$) trending towards heterogeneity of response by the EG, most likely due to a misinterpretation of signage. Moreover, some items showed significant variance differences but without mean score significance, and these included dedicated bike lane ($p = 0.003$), two-way cycle paths ($p = 0.047$), right turn hand signal ($p = 0.050$), and obligatory cycle paths ($p = 0.042$). In all of them, CG responses were more uniform, and EG participants had greater variability, indicating uneven understanding or vagueness in some traffic contexts. Even though mean differences were generally small, this consistent pattern of increased variance for the EG suggests where the intervention can be refined to increase precision and comprehension.

In the pre-simulator phase, Independent Samples t-tests were used to contrast differences between the Control Group and the Experimental Group for many traffic scenarios. The lone statistically significant result was in the question regarding biking on a pedestrian street, where Levene's Test registered unequal variances ($p < 0.001$), and the t-test (assuming unequal variances) was $t = -1.759$, $p = 0.046$. The CG proved to be superior to the EG with a mean difference of -0.275, which suggests control participants were better known or more confident in this scenario. All the remaining items reported non-significant results ($p > 0.05$) with no significant differences between the groups in most traffic conditions prior to the simulator intervention.

4.12. Repeated measure Anova

To compare the effectiveness of the traffic education intervention, a repeated measures ANOVA was conducted on both performance scores on the questionnaire and the simulator. Comparison between the experimental group (EG) and the control group (CG) of the performance over time (pre-test and post-test) was done.

The results had a significant main effect on three questionnaire items as presented in Table 1: red light at the intersection, priority to the car approaching from the right, and the cyclist's sign permits to go straight. These effects were further explored by analyzing pre- and post-test scores between groups. For red light at the junction, there was a significant main effect of Test ($F(1,29) = 5.45$, $p = .027$). That is to say that both the Control Group and Experimental Group acquired greater knowledge of red light behavior after the training. Members in both groups posted higher scores on the post-test than on the pre-test, indicating higher understanding of appropriate behavior at red lights after the intervention.

A significant main effect of Test ($F(1,29) = 4.26$, $p = .048$) was found for the right-of-way for the car coming from the right. This suggests that CG and EG participants learned more about the priority rules at intersections with a vehicle from the right. Again, no significant Group interaction was found, indicating that both groups learned equally well from pre- to post-test.

In the same, for the cyclist sign that allows to continue straight, there was a significant main effect of Test ($F(1,29) = 21.56$, $p < .001$), with considerable improvement from pre-test to post-test in CG and EG. This suggests that regardless of group, the intervention enhanced participants' accurate interpretation of this road sign.

On the other hand, for the different items e.g., dedicated bike lane ($F(1,29) = 0.002$, $p = .964$), hand signal to turn right ($F(1,29) = 0.003$, $p = .958$), green light at the intersection ($F(1,29) = 0.299$, $p = .589$), and priority to pedestrian at zebra crossing ($F(1,29) = 3.07$, $p = .090$) no pre-post changes were noted, and no Test × Group interactions. These results indicate that the training session generally improved rule comprehension for several key measures in both the CG and the EG, but no differential group effects were found. Both groups improved equally well over time, with no significant Test × Group interaction.

Table 1: Corrected F and probability values per questionnaire measure.

Item	**Effect**	**F**	**p**
Red light at the intersection	Test	5.45	0.03
	Test × Group	1.50	0.23
Priority to car from right	Test	4.26	0.05
	Test × Group	0.21	0.65
Cyclist sign to go straight	Test	21.56	<.001
	Test × Group	0.03	0.87
Dedicated bike lane	Test	0.00	0.96
	Test × Group	2.00	0.17
Hand signal to turn right	Test	0.00	0.96
	Test × Group	2.73	0.11
Green light at intersection	Test	0.30	0.59
	Test × Group	0.30	0.59
Priority to pedestrian at crossing	Test	3.07	0.09
	Test × Group	0.29	0.60
Bus stop sign	Test	1.76	0.20
	Test × Group	0.16	0.69
Give way sign for cyclist	Test	0.45	0.51
	Test × Group	1.97	0.17
Priority on bicycle street	Test	1.07	0.31
	Test × Group	1.07	0.31
Stop sign	Test	0.09	0.77
	Test × Group	0.95	0.34
Mandatory cycle path	Test	0.45	0.51
	Test × Group	1.97	0.17
Prohibition sign for cyclist	Test	0.14	0.71
	Test × Group	0.14	0.71
Cycle path stops	Test	6.28	0.02
	Test × Group	0.19	0.67
Yellow strip sign	Test	0.76	0.39
	Test × Group	0.76	0.39

The test had a significant main effect (pre vs. post) on traffic scenarios, particularly motor vehicle encounters and common street areas in simulator data, as presented in Table 2. Both groups improved across time for Scenario 4 (parallel car exits parking), with subjects reporting significantly different opinions at post-test compared to pre-test ($F(1,29) = 15.656$, $p < .001$). Although the Group (CG vs. EG) by Test interaction was statistically not significant ($F(1,29) = 3.539$, $p = .070$), the near significance suggests that Experimental Group (EG) participants may have learned more than Control Group participants. Besides, there was a significant main effect of Test for Scenario 6 (cycling street with motor vehicles), $F(1,29) = 7.675$, $p = .010$, whereby improvements were observed in both CG and EG but without interaction between group and time.

For Scenario 7 (cycling pedestrian street), there was a noteworthy time effect ($F(1,29) = 12.627$, $p = .001$), which represents enhanced perceived safety or behaviour postintervention for both groups, but no group interaction was noted. Scenario 13 (cyclist sorting) also showed moderate change over time ($F(1,29) = 5.541$, $p = .026$), with no noteworthy group interaction with CG and EG. Surprisingly, Scenario 2 (cyclist suggestion lane) registered a borderline significant Test × Group interaction ($F(1,29) = 3.995$, $p = .055$), which meant that Experimental Group participants learned more regarding giving way or cycling priority understanding in indirectly trained situations than Control Group participants. These findings imply that the intervention may have also had a more specific effect on EG participants in some situations where safety interpretation or behavioural awareness was required.

Table 2:Corrected F and probability values per simulator cycling measure.

Scenario	**Measure**	**F**	**p**
Shared cycling/pedestrian lane	Test	0.32	0.58
	Test × Group	0.00	0.99
	Group	1.27	0.27
Cyclist suggestion lane	Test	0.65	0.43
	Test × Group	4.00	0.06
	Group	0.00	0.99
Car in the way	Test	1.28	0.27
	Test × Group	1.28	0.27
	Group	0.59	0.45
Parallel car exits parking	Test	15.66	0.00
	Test × Group	3.54	0.07

	Group	0.98	0.33
Cycling street with car	Test	7.68	0.01
	Test × Group	2.57	0.12
	Group	0.62	0.44
Cycling on the street with pedestrian	Test	12.63	0.00
	Test × Group	2.85	0.10
	Group	0.55	0.47
Bus stop	Test	3.75	0.06
	Test × Group	0.85	0.37
	Group	1.89	0.18
Entry forbidden sign	Test	3.07	0.09
	Test × Group	0.29	0.60
	Group	0.02	0.89
Car from the right (no priority)	Test	0.32	0.58
	Test × Group	0.00	0.99
	Group	0.08	0.78
Stop sign	Test	2.27	0.14
	Test × Group	0.76	0.39
	Group	0.20	0.66
Sign allowing cyclists through a red	Test	0.36	0.55
	Test × Group	0.03	0.86
	Group	0.45	0.51
Cyclist sorting area	Test	5.54	0.03
	Test × Group	0.16	0.69
	Group	0.16	0.69

Analysis of average questionnaire data score in Table 3 revealed a significant main effect of time ($F = 9.38$, $p = .005$, partial $\eta^2 = .244$), which indicates that participants' scores increased from pre- to post-test across all groups. The Group × Time interaction was insignificant ($F = 0.60$, $p = .445$, partial $\eta^2 = .020$), meaning the experimental group improvement was not significantly greater than the control group. Additionally, the overall effect of the group was non-significant ($F = 2.253$, $p = .144$, partial $\eta^2 = .072$), yet a small to moderate effect size indicates that there might be some trend. These results suggest that the training was generally practical, but the intervention did not have a significantly more substantial effect on the experimental group.

Table 3: Corrected F and probability values per average questionnaire measure

Scenario	Effect	F Value	p Value	Partial η^2
Average score for the questionnaire	Time (Pre vs Post)	9.38	0.005	0.24
	Group × Time	0.60	0.445	0.02
	Group (Overall Mean)	2.25	0.144	0.07

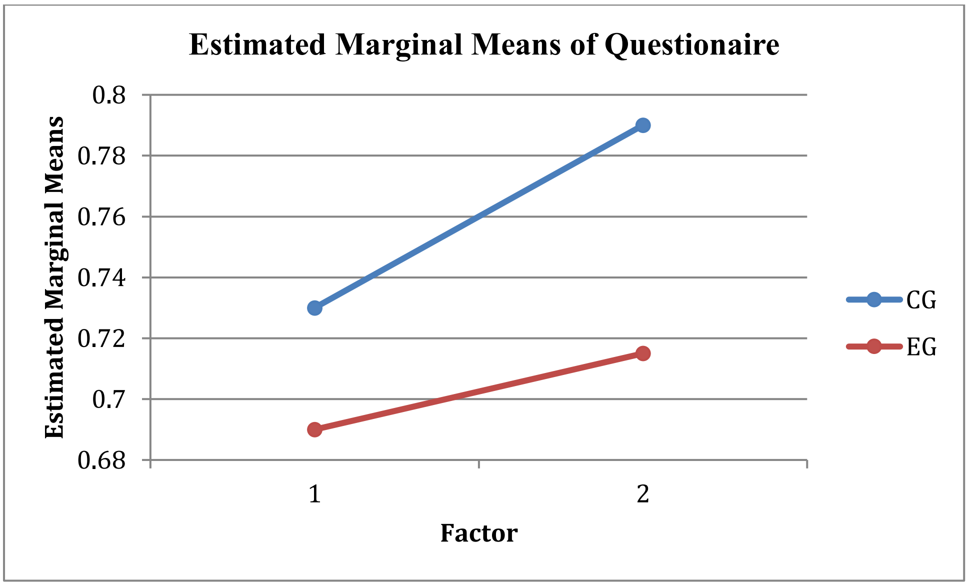

Figure 33: Estimated Marginal Means of Questionnaire Performance by Group (Control vs. Experimental) Across Pre- and Post-Test

Figure 33 displays estimated marginal means for the control and experimental groups at two time points (pre- and post-test). Initially, the control group was slightly higher (0.735) than the experimental group (0.695). Both groups improved over time, and the control group improved more significantly to 0.790, while the experimental group improved to 0.715. The plot shows that both groups have improved, but the control group has gained more. This graph, however, does not display statistical significance.

As shown in Table 4, the analysis of the average simulator scenario score revealed a significant main effect of time, indicating that participants improved their scores from pre- to post-test ($F = 22.323$, $p < .001$, partial $\eta^2 = .425$). Additionally, there was a significant time-by-group interaction ($F = 7.170$, $p = .012$, partial $\eta^2 = .137$), suggesting that the experimental group improved more than the control group. Although the overall group effect was not statistically significant ($F = 2.179$, $p = .151$, partial $\eta^2 = .070$), the effect size is small to moderate in direction. It would likely emerge with a larger sample or longer intervention. Together, these findings affirm that the training intervention positively impacted cycling behavior, especially over time.

Table 4: Corrected F and probability values per average score for the simulator

Scenario	**Effect**	**F Value**	**p Value**	**Partial η²**
Average score for simulator	Time (Pre vs Post)	22.32	< .001	0.43
	Group × Time	7.17	0.012	0.14
	Group (Overall Mean)	2.18	0.151	0.07

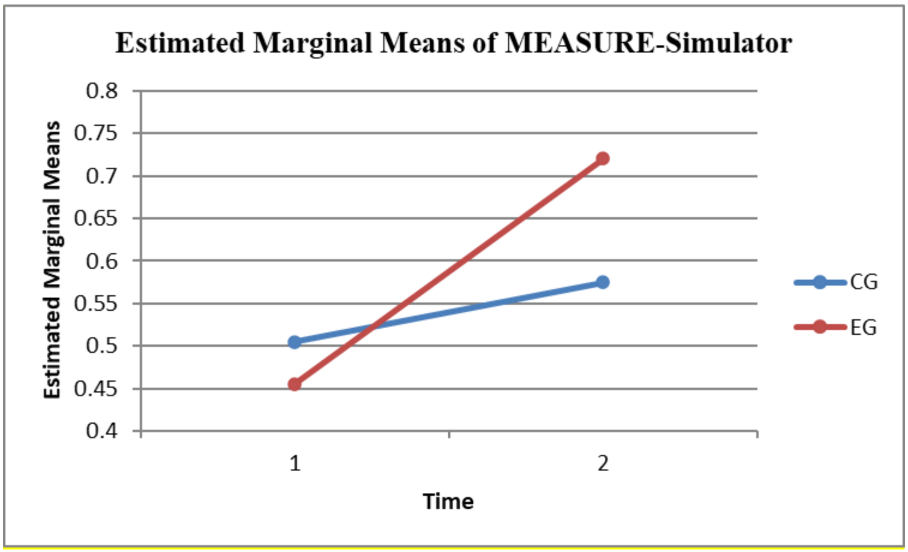

Figure 34: Estimated Marginal Means of Simulator Performance by Group (Control vs. Experimental) Across Pre- and Post-Test

Figure 34 is a graph of estimated marginal means for experimental and control groups on pre- and post-test. The control group started slightly higher, but both started equally. At post-test, the experimental group showed significantly more improvement (from <0.45 to >0.73), while the control group showed a tiny increase (from 0.50 to 0.57). This indicates that the intervention significantly boosted performance in the experimental group.

5. Discussions

The aim of this study was to evaluate the cycling behavior among Hasselt University's new international students from various countries worldwide, with the exception of Belgium, in a cycling simulator. The purpose was to find out whether an educationally specific intervention could be found to be effective in enhancing international students' knowledge of traffic regulations and safe cycling etiquette in Belgium. Apart from this, the study also assessed whether outcomes varied with group allocation (experimental or control). Participant questionnaire response provided valuable information on participants' baseline knowledge of Belgian road traffic rules and the extent of improvement following administration of the intervention. This research was also to assess whether access to a simulator-based cycling education program would result in measurable alterations in cycling conduct. The simulator offered a controlled and realistic setting for testing participants' live reactions to different traffic conditions, something not possible with self-reported questionnaire assessment.They offered an objective evaluation of behavioral change. The simulated metrics supplemented the survey data and allowed for a comprehensive evaluation of the intervention effectiveness.

5.1. Questionnaire

Pre-test questionnaire results revealed no statistically significant difference in baseline knowledge between the experimental group (EG) and the control group (CG). The finding suggests that both groups understood traffic rules and cycling safety equally, likely due to their shared status as international students unfamiliar with the local traffic environment. These results add weight to the argument for compulsory traffic education courses for newly arrived residents from countries where road safety norms and cycling cultures differ.
Gender trends were evident in the questionnaire data, interestingly. Male cyclists displayed higher rates of dangerous behavior and more offenses (V) than female cyclists. According to previous research, males also reported higher participation in traffic-related crashes (e.g., Vanparijs et al., 2015; Useche et al., 2021), demonstrating that men take more deliberate risks while cycling. They are generally attributed to behavioral factors such as overconfidence, thrill-seeking, or lowered risk perception, which may contribute to higher accident rates.

The data also showed that males scored more on the composite risk behavior scores (Errors + Violations), adding strength to the implication that male young cyclists may require targeted interventions focusing on knowledge and behavior modification. These findings are supported by the study of Tsuboi et al. (2018), where they point out the link between male cycling behavior and an increased likelihood of crashes in urban settings. Interestingly, the control group exposed only to everyday theory teaching slightly improved post-test knowledge, suggesting that even minimal educational exposure can be helpful. However, the greater improvements in the experimental group suggest the added value of including such practical, interactive elements as simulation, which can enhance engagement and real-world use of traffic knowledge.

Together, the questionnaire findings identify the potential of comprehensive traffic education programs with cognitive and behavioral components. Addressing the specific interests of risk-susceptible groups, male cyclists and newly arrived residents unfamiliar with local traffic laws, for example, can bring about more effective learning effects and contribute to the formation of safer urban mobility environments in the long term.

5.2. Simulator

Early results of the pre-testing of the simulator were that both the control group (CG) and experimental group (EG) participants had similar baseline behavior when it came to violations, errors, and hazard perception. This was in line with uniformity in rating their pre-test questionnaire, further asserting that international students usually begin with little knowledge and preparation in navigating Belgian traffic rules as cyclists.

Improvement was most evident for the experimental group in how they responded to risky situations, such as traversing intersections, reacting to pedestrian crossings, and coping with traffic lights. The subjects were more careful and adhered to road rules more stringently in the post-test scenarios. Although all the statistical tests did not show a significant interaction between time-group, trends in descriptions, and effect sizes reveal the intervention did have a real-world effect on behavior, if statistical power was compromised by a moderate sample size.

Second, consistent with the literature (O'Hern et al., 2017; Rezaei et al., 2021), the simulator allowed participants to attempt and learn from mistakes in a consequence-free environment. This experiential feedback loop is a major strength of simulation-based training, enabling users to adjust behavior in response to immediate feedback. As an example, a user who failed to yield at a simulated roundabout might re-drive the scenario following feedback, re-enforcing correct behavior through repetition and guided practice.

Gendered behavioral patterns also emerged in the simulation records. Male participants, overall, experienced higher frequencies of risky driving maneuvers such as sudden turns, lane incursions, and late braking in the pre-test phase. Such maneuvers align with gender differences in traffic behavior studied, where men are overconfident and risk-taking (Useche et al., 2021). Though male participants in the experimental group also showed significant improvement after intervention, gender differences in performance remained, suggesting that simulator training needs to be supplemented with other interventions for behavioral modification, especially in high-risk subgroups.

One of the major benefits of the simulator was that it could be used to standardize the testing conditions. In contrast to field-based testing, all subjects were presented with the same conditions under uniform conditions, which precluded variations in traffic, weather, or extraneous distractions. This builds the strength of the demonstrated changes in behavior and further supports the use of the simulator as an instruction and assessment tool.

Overall, the simulator data indicated that experiential feedback-based training is a major contributor to enhancing behavior in cycling safety. While the acquisition of knowledge (via questionnaire) is required, altering behavior needs to be an active process comprising practicing and reinforcement elements that the simulator could provide. These findings lend support to the integration of simulation within broader-scale traffic education programs, particularly where groups with diverse cultural backgrounds are involved and less familiar with local road environments.

6. Limitations and recommendations for future research and policy recommendations

6.1. Limitations and recommendations for future research

Despite its helpful outputs, this study has some limitations. First, the sample size was small, only 31 subjects after outliers were dropped. This reduced number affects the statistical power of the findings and restricts the ability to extrapolate findings to the broader population of international students. As quoted from standards of behavioral research, a larger sample (in most cases, N > 100) would be required to estimate interactions between variables like speed, error rate, and risk-taking behavior with confidence (Cohen, 1988).

Second, the period of evaluation was short-term. Although the post-test was given a week after the intervention, one cannot be certain that the behavioral changes that were seen would persist in the long run. Longitudinal studies would be needed to ascertain retention of learning and long-term behavioural change.

Another limitation is with the ecological validity of the simulator. While it simulates on-road reality, it does not fully substitute for the sensory, affective, and idiosyncratic elements of actual road cycling. Some of the participants had complaints of acclimatization to the simulator, including motion sickness and the learning process that could have influenced their performance, and did not show up due to sickness problems.

The study also grouped all foreign students in a single category without considering differences in traffic culture and cycling experience from their home countries. Such background differences could have influenced their baseline knowledge and responsiveness to training, but were not analyzed in detail. Lastly, the experiment did not consider natural conditions such as weather, daily distractions, or social influence by peers, which could have a significant influence on cycling behavior in natural settings.

Another limitation is that the topic is very innovative, so this leads to a lack of literature related specifically to the topic.

Based on the findings of this study, several recommendations are forwarded. First, future research should aim to use a larger and more representative sample size, ideally more than 100 participants, to maximize statistical reliability and generalizability. Having balanced representation from gender, age, and ethnic backgrounds, both from the European and non-European student groups, would provide a deeper perspective of cycling behavior among diverse demographic groups.

Extending the methodological design to the inclusion of real-world cycling experience and tasks performed in the simulator is also recommended. While simulators provide a safe and controlled environment for testing, on-road cycling trials have the potential to offer more insight into the cyclists' reaction to dynamic and unpredictable road conditions. This multi-methodology would enhance the ecological validity of the findings and assist in demonstrating the effectiveness of simulator training. Second, using more advanced data monitoring tools, such as motion monitoring, live error logging, and more feedback systems, can increase simulator accuracy and comprehensibility.

6.2. Policy Recommendations

Operationally, several policy-initiated activities need to be in the works to advance the protection of foreign students cycling in Belgium. A key starting point is for universities to make cycling safety instruction part of their formal orientation courses for incoming foreign students. These orientations need to go beyond generic lectures and incorporate interactive learning modules through cycling simulators and virtual reality tools. Such simulated environments can replicate real traffic conditions in Belgium and make students familiar with the local cycling laws, road signs, right-of-way rules, and local infrastructure in a safe and shielded environment.

To enable efficient delivery and scalability, there is a requirement for coordination between national road safety organizations, municipal governments, and universities. Coordination can facilitate the development and funding of standardized VR-based cycling safety courses and share access to refreshed simulation technology and learning platforms. In addition, policymakers need to consider the institutionalization of the Cycling Behaviour Questionnaire (CBQ) as a standard assessment instrument in all institutions with high numbers of international students. The CBQ, as observed in this study, provides a tested measure of cyclist knowledge, behavior, attitudes, and perceptions of risk before and after safety interventions. CBQ results, set out in the results section, demonstrated measurable changes in behavior among participants who had received simulator-based training, lending credibility to its application as an assessment tool for future interventions.

Other recommendations include the implementation of cycling mentorship initiatives, whereby experienced local students or cycling ambassadors escort newcomers during their initial weeks on the road. Such informal but structured peer support provisions can reduce stress, build confidence, and promote safe cycling behavior. Furthermore, universities and municipalities need to work together to provide additional multilingual cycling signs along campus and student district roads, so that critical road directions are not misread due to language misunderstanding.

Local authorities need to introduce subsidy or leasing programs that make safety gear—particularly helmets and lights free or affordable for international students. Since the study found helmet use was quite low (41.9%), there was a requirement for more promotion through policies and accessibility. Through continuous publicity campaigns, these programs would reinforce the culture of safety and compliance among international cyclists.

Finally, to sustain and increase these activities, there must be yearly evaluation of cycling accidents among international students and associated with educational reform. CBQ feedback and accident reports can be used to revise training material and adjust interventions to emerging risk behaviors in order to continue improving the safety and integration of international students into Belgium's cycling culture.

7. Conclusion

This study evaluated the effects of a simulation-supported traffic education program intended to improve cycling behavior and traffic rule awareness among foreign students in Belgium. The intervention was intended to improve coping with safety problems associated with foreign cyclists who were not adapted to the local traffic environment. Pre- and post-test questionnaires and simulator-based tests were used for comparison between a control group and an experimental group, with the latter subject to scenario-based simulator training with feedback. The findings suggested that the experimental and control groups had improved knowledge of traffic rules over time, notably in red light behavior, right-of-way at intersections, and interpretation of road signs by cyclists. However, there was no suggestion that the experimental group had acquired greater knowledge than the control group on self-reported questionnaire data. But measurements based on simulators showed clearer-cut benefits of the intervention. The experimental participants demonstrated greater gains in responding to traffic situations, including parallel parking exit situations, cycling streets with motor vehicles, and shared pedestrian/cycling zones. Most notably, there was a statistically significant Group × Time interaction in the overall simulator scores. The interactive scenario-based training apparently increased behavioral change levels compared to methods based on approaches alone.

Demographic measures such as history of accidents and age showed trends in accordance with prior research that accidents predicted more bad behaviour, while older participants tended to perform better. None of these trends was significant, though. Gender was not found to be consistently or significantly related to bad behaviour.

Although there was a small sample and technical issues, the outcome shows the potential of simulation-based training as a worthwhile tool to improve international student bicycle safety. Future research would demand larger and more diverse populations and include actual-life follow-ups to establish the long-term impact of training. In all, this study confirms the need for immersion-based, evidence-led education in preparing foreign cyclists to ride safely across complex traffic conditions.

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Appendix

A. Pretest Questionnaire (For Both Control and Experimental groups)

Participant ID number:

My name is UKWIZAGIRA Gaspard, and I am studying for a master's in Transportation Sciences at Hasselt University in Belgium. The survey aims to understand how to investigate the behavior of cyclists in a cycling environment by discovering defects that can initiate road accidents.

The survey will take less than 10 minutes to complete. Your participation in this survey is greatly appreciated, and I would like to assure you that all your responses will be kept confidential. There are no right or wrong answers; you must answer each question honestly.

Please read the information below thoroughly.

- I have read the above information about this survey.
- I understand the purpose of this survey and what is expected of me in this survey.
- I understand that my participation in this survey is voluntary.
- I have the right to discontinue my participation in the survey at any time without giving any reason.
- I understand that the results of this survey may be collectively used for scientific purposes and may be published.
- I understand that my name will not be published, and the confidentiality of my data is guaranteed at every stage of the survey.
- For questions, I know I can contact after my participation: gaspard.ukwizagira@student.uhasselt.be
- For any complaints or other concerns regarding the processing of personal data, I can contact the UHasselt data protection officer at dpo@uhasselt.be

o I agree and would like to fill in the survey
o I disagree and would not like to fill in the survey

1. Gender:
    a. Male
    b. Female
    c. Non-binary
    d. I prefer not to mention it.
2. How old are you?

3. Educational background
    - Less than a high school diploma
    - High school diploma
    - Bachelor’s degree
    - Master’s degree
    - Doctorate
    - Others (Please specify).
4. What is your nationality?
5. How long do you live in Belgium?
6. Occupation/jobs
    - Student
    - Employed
    - Entrepreneur
    - Disabled
    - Other (Please specify).
7. Which mode of transport do you most often use to travel in Belgium?
    - Foot
    - Bicycle
    - Cars
    - Scooters
    - Buses
    - Others
8. How often do you cycle in Belgium?
    - Daily
    - Several times a week
    - Once a week
    - Several times a month
    - Once a month
    - Several times a year
    - Once a year
    - Never
9. For what purposes do you cycle? (Select all that apply)

- Commuting (School/work)
- Recreational
- Fitness/sport
- Errands/Shopping
- Saving money on transportation
- Environmental reasons
- Mental well-being/Stress relief
- Other (please specify)

10. What is the bike ownership status in your household? Select all that apply.

- Do not own a bike.
- Rent a bike on a permanent basis.
- Use bike sharing.
- Own bike

11. Which kind of bike do you cycle most often?

- Standard
- Electric
- Others

12. Do you wear a cycling helmet?

- Never
- Rarely
- Sometimes
- Often
- Always

13. Do you wear a fluorescent jacket while cycling when it is dark?

- Never
- Rarely
- Sometimes
- Often

- Always
- Not applicable: I do not cycle when it is dark

14. How would you rate your understanding of cycling safety rules and practices?

- Very good
- Good
- Neutral
- Bad
- Very bad

15. Do you feel safe while cycling in Belgium?

- Totally yes
- Yes
- Neutral
- No
- Totally not

16. How often have you been involved in a traffic accident while cycling in Belgium?

- 0
- 1
- 2
- 3
- More than 3 times

16.1. If not ‘0’, what are the accident's characteristics? (multiple answers possible)

- Off-road
- Falling due to a poorly paved cycle path
- Collision with pedestrians
- Collision with another cyclist
- Collision with a vehicle
- Collision with a motorcycle
- Distracted (if yes, indicate by:)
- Under the influence of alcohol

- If there is another, please specify.

16.2. Only if not ‘0’, what are the consequences of an accident happening? (multiple answers possible)

- Severe injuries
- Light injuries
- Material damage
- No damage /No injuries

16.3. Are the accidents reported to the police?

- Yes
- Minimum one
- No

17. Did you charge any traffic fines?

- Yes
- No

17.1. How often did you charge a traffic fine?

- 0
- 1
- 2
- 3
- More than 3

17.2**.** What is the reason for traffic fines?

- Speeding
- Drink driving
- Red running
- Traffic violations
- Illegal parking
- Illegal overpass
- Wrong way cycling

18. Have you followed traffic education in Belgium?

- Yes
- No

18.1.If yes, how often?

- Once
- Twice
- More than two

18.2.How was traffic education delivered?

- Online
- Physical
- Both

19. What should you do if there is a dedicated bike lane

- **Ride in the bike lane if safe and available1**
- Ignore it and ride on the road
- Use it only when the road is busy
- Stop riding

20. What hand signal should you use to indicate a right turn?

- Extend your left arm straight out
- **Extend your right arm straight out**
- Point to the ground with your right hand
- No hand signal needed

21. What does this green light at an intersection mean?

- **Cyclists are allowed to cross without waiting**
- Cyclists are not allowed to cross at this location
- Cyclist must wait for other traffic to pass
- I do not know

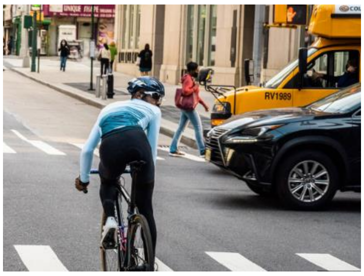
22. Should you cycle straight at this intersection when there is a red light?

- I have to wait for the yellow right before crossing
- I have to cross the road immediately
- **No answer is correct**
- I do not know

23. Should you, as a cyclist, give priority to the pedestrians who want to cross at the zebra crossing?

- No, I have a priority rather than a pedestrian
- **Yes, I have to give priority to the pedestrians**
- I have to wait always
- I do not know

24. Do you have a priority for the car coming from the right?



- **Yes, I have a priority**
- Maybe
- No, the car has a priority
- I do not know

25. What is the meaning of these signs?

- **Cycle paths in two directions**
- Cycle paths in one direction
- No cycle paths here
- I do not know

26. What should you do at the bus stop where passengers get off and get on?

- **Slow down and give priority to them**
- Ride quickly because I have a priority
- I have to stop at the bus stop
- I do not know what to do

27. What you should do at this signpost as a cyclist

- You have to change the direction
- **Continue straight forward**
- Give priority to other traffic coming in the opposite direction
- I do not know

28. What is the information provided by these signs?

- **Give way; watch out for cyclists from left and right**
- Continue forward without waiting
- Stop at 100 m before reaching the sign
- I do not know

29. Do you have a priority on this road?

- I have not a priority on this road, it is for motorized traffic
- **I have a priority in this road because it is bicycle street**
- May be this road is for cyclist
- I do not know

30. What do you have to do on this signpost?

- Slow down at 100 m before reaching the sign
- **Stop and give way to other road users**
- Keep going forward

- I do not know

31. What does this sign mean?

- Cyclists must yield to oncoming traffic
- **Cyclists have the right of way at this crossing.**
- Cyclists must stop before crossing.
- I do not know

32.What does this sign mean?

- This is a designated cycling street, giving priority to cyclists.
- Cyclists must use a separate cycle path if available.
- Motor vehicles are prohibited on this street.
- I do not know

33. What does this sign mean?

- Cyclists must yield to oncoming traffic.
- Cyclists have the right of way at this crossing.

- Cycling is prohibited on this road or path.
- I do not know

34. The cycle path stops here, where should you continue cycling if you are older than 10 years?

- **On the road**
- On the footpath
- I go back to look for another cycle path
- I do not know

35. Did the car leaving its parking space have priority?

- Yeah, It has a priority
- No, It has not a priority
- The car must allow the cyclist to pass
- I do not know

The car left its parking space and did not have a priority, but it left anyway. So always pay attention to the sign that a vehicle wants to leave (e.g, Indicators)

36. What does this yellow strip mean?

- A cycle path
- A parking lane for cars
- **A bicycle lane**
- I do not know

This yellow strip is a suggested bicycle lane so that you may cycle there. So be careful because this is not a bicycle path; cars can drive and park there.

B. Additional questionnaire for experimental group

Participant ID number:

1. Gender
    - Male
    - Female
    - Non-binary
    - I prefer not to mention it.
2. How old are you?
3. What is your nationality?
4. How would you rate your overall experience with this simulated cycling education (i.e., feedback during simulation)?
    - Very positive
    - Positive
    - Neutral
    - Negative
    - Very negative
5. How would you rate the effectiveness of this education used?
    - Extremely effective
    - Very effective
    - Moderately effective

- Slightly effective
- Not at all effective

6. Did you find the education helpful in improving your cycling skills?
    - Totally Yes
    - Yes
    - Neutral
    - No
    - Totally no
7. How confident do you feel about applying what you learned about cycling in real-life scenarios?
    - Extremely confident
    - Very confident
    - Moderately confident
    - Slightly confident
    - Not confident
8. Which specific cycling skill do you feel improved the most? (multiple answers)
    - Balance and bike control
    - Pedaling efficiency
    - Road safety awareness
    - Endurance and stamina
    - Gear shifting and braking techniques
    - Other
9. How likely are you to recommend this cycling simulator education to others?
    - Very likely
    - Somewhat likely
    - Neutral
    - Unlikely
    - Very unlikely
10. Do you have any additional comments or suggestions regarding this education (e.g., signs/situations that are missing)?