An analysis of higher-order cycling skills in primary school children in the Netherlands

Marie Xhauflair
S2995433

Faculty of Behavioral, Management, and Social Sciences, University of Twente
Educational science and technology

1st Supervisor: Dr. Erik Roelofs
2nd Supervisor: Dr. Johannes Steinrücke

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Abstract

The WEVER project, is a test suite developed to evaluate the mandatory primary school traffic education programs in the Netherlands by assessing four higher-order cycling skills (HOCS). These essential cycling skills include decision-making at intersections (DMI), hazard perception (HP), gap acceptance (GA) and morally acceptable cycling behavior (MACB).

Using a descriptive and explanatory approach, an analysis was conducted with data collected in 2020 and 2022 from the WEVER test. The analysis examined the demonstration of each higher-order cycling skill, bike use, and collision involvement across years and provinces in the Netherlands. Furthermore, the impact of perceived traffic education at school and at home on higher-order cycling skills was investigated. Finally, the role of traffic education and cycling skills in predicting collision involvement was analyzed. The overarching goal was to provide insights into how traffic education contributes to the development of higher-order cycling skills and the safety of young cyclists.

The findings suggest that many children still lack fundamental cycling skills. Formal traffic education is paradoxically associated with a higher collision risk, while informal traffic reduces it. Given schools' important role in the development of HOCS and the implementation of traffic education curricula, there is a clear need to analyze and assess traffic education curricula due to their contribution to cycling safety and skill development. Furthermore, initiatives to support parents in educating their children on each of the four HOCS to help reduce unsafe traffic situations may be beneficial.

Keywords: Higher-order cycling skills; Dutch traffic education; cycling safety in the Netherlands; WEVER project

Foreword

While writing this thesis, I found myself reflecting on my occasionally terrible cycling behavior. When committing infractions, we may not fully realize the consequences they may have on others (especially the little ones) and on ourselves. So not only did this research show me that, actually, a large percentage of people do not know how to cycle safely, but also that I ought to do better.

I have banned the words “soon”, “almost there”, and any of their distant or not so distant worded cousins. It is time I unban them myself. With certainty, I can say: “Soon, I will finish. It really is the end of my master era.”

Thank you to my parents, often being more excited about my writing than I was, always asking many, many questions about what I was finding out, and of course, for always being very supportive.

Thank you to Dan, Marianna (and Frido too), for the time we spent playing cards instead of me writing the thesis, for always doing or saying something to make each other laugh and feel better, and for being there for each other. For the dreams and the fantasies. Living far apart but never being too far away.

Thank you to Elena, with whom I can always count on to tell the truth, push me when I need it, walk around cemeteries with (because thank goodness we're alive), and for wishing me to always be the color or shape I am.

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1. Introduction

The Netherlands is known for its cycling culture and extensive cycling infrastructure. Examples include cycling highways, multi-level bike parking, bike-specific priority lanes, and designated traffic lights. Based on research conducted in 2022 that surveyed 28 countries worldwide, 65% of Dutch residents bike at least once a week, ranking third and surpassing the average of 35% by a substantial margin (Ipsos, 2022). Additionally, 72% of Dutch residents own a bike, placing the Netherlands first in bike ownership among the 28 countries surveyed, far above the average of 42% (Ipsos, 2022).

While biking is common and perhaps the norm in the Netherlands, the statistics related to cycling accidents and fatalities are reason for concern. According to a comparative report by the European Commission (2021), the Netherlands reports 8.5 cyclist fatalities per million inhabitants in the period from 2017 to 2019, the second-highest cycle fatalities within the European Union (EU). Moreover, the percentages of cyclist fatalities in relation to the total number of all road user fatalities place the Netherlands in the top position, accounting for 26% of total fatalities (European Commission, 2021). Importantly, the occurrences of cycling injuries in the Netherlands increase from the age of 12 onwards. Why this is the case is not yet fully understood and requires further investigation (Twisk & Vlakveld, 2019).

One hypothesized explanation is the transition phase from primary to secondary schools, during which increased commuting distance is coupled with an underdeveloped set of cycling skills essential to navigate in traffic (Twisk & Vlakveld, 2019). While it may be inevitable for secondary school students to cycle longer distances, the concept of underdeveloped complex cycling skills refers to skill acquisition, which can be targeted and improved through the early years of primary education.

In response, the WEVER project, abbreviated from “Op Weg naar Effectieve VERkeerseducatie” in Dutch or “Road to Effective Traffic Education” in English, was formed in 2015 by a few organizations (namely: the *Royal Haskoning DHV,* SWOV*,* CITO, and Kennisplatform CROW) to evaluate the Dutch traffic education in schools. Within the context of the project, four higher-order cycling skills (HOCS) were identified, which subsequently were decided to be monitored through the WEVER test suite. Each subtest within the suite assesses one of the HOCS. The test suite is used to assess children’s cycling skills resulting from the Dutch traffic education curriculum (Kennisprogramma Verkeer en Vervoer, n.d.). These skills relate to how one might integrate multiple types and sources of information, anticipate various events, and effectively switch between focused and divided attention, thereby attending to the relevant stimuli and ignoring distracting ones (Twisk & Vlakveld, 2019).

Within the WEVER project, data were collected in 2017, 2019, 2020, 2022, and 2024. (Kennisprogramma Verkeer en Vervoer, n.d.). So far, only Twisk et al. (2018) evaluated the outcomes of traffic education in primary schools using the results of the WEVER test gathered in 2017. However, since then, no other scientific papers that investigated the results of the test outcomes and higher-order cycling skills in children could be identified (at the time of writing this thesis). There are four aims of this study. First, this thesis aims to gain descriptive insights into bike use, and children's collision involvement, and second it aims to gain descriptive insights into the demonstration of HOCS. Next, the thesis investigates the role of traffic education at home and school in the demonstration of HOCS. Lastly and most importantly, the thesis aims to investigate potential predictors and outcomes of children's safety on the road while biking through correlational analyses while controlling for third variables including children's characteristics, bike use, HOCS, and traffic education, contributing to the theoretical understanding of influences on road safety.

2. Theoretical framework

2.1. Cycling safety concerns

Cycling injuries in the Netherlands increase from age 12 onwards (Twisk & Vlakveld, 2019). One explanation for this is the longer commuting distances that young cyclists have to travel to secondary school, which implies higher traffic exposure resulting in a higher accident risk (Twisk & Vlakveld, 2019). In 2020, the Netherlands recorded that primary school children in the age group of 6 to 12 years covered a weekly bike distance of 15.2 kilometers (Ipsos, 2022). In contrast, the subsequent age group of 12 to 18 years recorded the highest average weekly biking distance of all age groups in the Netherlands, covering 32.9 kilometers (Ipsos, 2022). Consequently, the distance difference between these two groups marks a steep and sudden incline, increasing the likelihood of encountering difficult and dangerous situations due to increased road exposure (Twisk & Vlakveld, 2019).

According to Twisk et al. (2018), cycling in traffic requires highly developed complex skills. The development of these skills is essential for safe cycling behavior. These skills include the ability to perceive risks, adopt a third-person perspective, and switch between divided and focused attention (Gregersen and Bjurulf, 1996; OECD-ECMT, 2006, as cited by Twisk et al., 2017). Conversely, poor cycling proficiency may result in children's heightened risk of collisions and fatalities on the road (Vanparijs et al., 2016).

Cycling skills, like other skills, can be acquired through practice and education, both formal and informal. In formal education, learning is done in a structured environment with clear and defined learning outcomes and approaches, often outlined in a curriculum (Burghardt & Hecht, 2020), such as the designated traffic education curriculum in the Netherlands. In informal education, learning is typically done in a less structured environment with no previously defined learning goals (Burghardt & Hecht, 2020). Informal education is closely related to the principles of social learning theory, which involves gaining skills, knowledge, and attitudes through observations, leading to the acquisition of complex behavior patterns, imitation, and modeling (Bandura, 1969). For example, when a parent crosses a red light with their child, the child observes the behavior and is more likely to reproduce it.

2.2 Traffic education in the Netherlands

The Dutch Ministry of Infrastructure and Environment (MIE) is responsible for developing traffic education and cycling skills (Mütze & de Dobbeleer, 2019). Under their jurisdiction and through close collaboration with provinces, municipalities and several stakeholders, efforts are made to further enhance cycling safety through traffic education at school (Government of the Netherlands, n.d.). The major stakeholders include the Dutch non-governmental safety foundation (*Veilig Verkeer Nederland*, VVN), the regional governmental safety organizations (*Regionaal Organen Verkeersveiligheid*, ROV); and the Dutch scientific research institute on road safety (*Wetenschappelijk Onderzoek Verkeersveiligheid*, SWOV).

Traffic education at school, thereby being formal education, is directed to improve skills to foster safe cycling behavior and a positive cycling attitude (Mütze & de Dobbeleer, 2019). It also aims to help students learn and understand traffic rules and develop important cycling skills (Mütze & de Dobbeleer, 2019).

In the Netherlands, traffic education is subsumed under one of the core learning outcomes as specified for the domain of Orientation to Self and World, specifically under the theme of People and Society: “Students learn to behave responsibly both socially, and as road users and as consumers.” (SLO, n.d.). Because of this, traffic education is a compulsory part of the primary school curriculum (SWOV, 2024). It has been a mandatory part of the curricula since 1959 (Staples, 2018). In practice, students have a dedicated 45-minute class each week to learn about traffic safety and practice their (cycling) skills (Mütze & de Dobbeleer, 2019).

2.3. WEVER

In 2015, the WEVER project was commissioned by the *Interprovincial Consultation of the Netherlands* (in Dutch known as “IPO”). It was carried out within a consortium of four non-governmental organizations including the *Royal Haskoning DHV,* SWOV*,* CITO*,* a Dutch educational assessment organization, and Kennisplatform CROW (*Centrum voor Regelgeving en Onderzoek in de Grond-, Water- en Wegenbouw en de Verkeerstechniek)*. The project was supervised by the Kennisplatform CROW, which is a Dutch knowledge institute focused on infrastructure, traffic, transport, and public space. Kennisplatform CROW is particularly known for its guidelines on traffic safety, road design, and public space, such as the manual for traffic facilities and the guidelines for bicycle and pedestrian infrastructure.

WEVER was initiated in 2015, to monitor traffic education interventions regarding the design quality, the coverage of learning objectives, and effectiveness in terms of accomplished learning outcomes in the Dutch provinces (Twisk et al., 2017). To that end, two major activities were undertaken. First, a checklist was developed to evaluate the quality of traffic education interventions, assessing several aspects of instructional materials and activities. Second, a computer-based assessment suite was developed to measure the effectiveness of the traffic education interventions in developing the essential cycling skills among grade 6 students (Hukker & Vissers, 2023).

The first report defined the cycling skills young cyclists should possess by the end of primary school (Hukker & Vissers, 2023). It concluded that safe cycling is more than just knowing traffic rules and having bicycle control skills (Hukker & Vissers, 2023). Rather, safe cycling is linked to four higher-order cycling skills (HOCS): decision-making at intersections, hazard perception, situational awareness, gap acceptance, and morally acceptable cycling behavior (Hukker & Vissers, 2023). These higher-order cycling skills, defined in 2015, guided the development of the WEVER test suite in 2016, designed to assess the extent to which children have acquired the essential skills for safe and responsible cycling.

The test suite contains six subtests: one for each HOCS, as well as a subtest for collecting data on student characteristics which includes information on student bike use, involvement in collisions, and evaluation of traffic education at home and at school, and the last subtest is an evaluative questionnaire (Kennisprogramma Verkeer en Vervoer, n.d.). The test suite underwent multiple iterations to enhance the reliability and validity of items. More detailed explanations are provided in the section on data collection (under section 3.3). Test data were collected in 2017, 2019, 2020, 2022, and 2024, across schools in various provinces in the Netherlands that participated in the WEVER project. In 2022, the test suite reached its final content and test assembly (Kennisprogramma Verkeer en Vervoer, n.d.).

2.4. Higher-order cycling skills

Table 1 presents an overview of the established higher-order cycling skills: decision-making at intersections, hazard perception, gap acceptance, and morally acceptable cycling behavior. It includes brief definitions and references to relevant studies for each skill. Furthermore, sections 2.4.1 to 2.4.4 elaborate on each higher-order cycling skill.

Table 1

Summary of the higher-order cycling skills and relevant studies

High-order cycling skills	Definition	Application	Relevant studies
Decision-making at intersections (DMI)	Involves a cyclist's ability to make decisions when preparing, planning, and executing cycling tasks at intersections, correctly applying traffic rules, and adjusting their own cycling behavior according to the road situation.	Applying rules of right of way or order of precedence	Barton & Morrongiello (2011); Hukker & Vissers (2023); Liikenneturva (2023); Schaefer et al. (2008)
Hazard perception (HP)	Centers on a cyclist's ability to perceive salient elements in their environment, and comprehend the potential risks these may present, understand how they can influence their safety, and impact cycling behavior.	Perceiving dangers on the road in a timely manner	Crundall et al. (2012); Endsley (1995); Hill et al. (2000); Hukker & Vissers (2023); Oron-Gilad et al. (2011); Twisk et al. (2018)
Gap acceptance (GA)	Part of risk acceptance, it refers to a cyclist's ability to evaluate whether a gap in traffic is safe to enter, cross, or merge into.	Ensuring sufficiently large safety margins to cross a road (gaps)	Chihak et al. (2010); Ellis (2014); Hukker & Vissers (2023)
Morally acceptable cycling behavior (MACB)	Refers to adherence to traffic rules and consideration for other road users, promoting mutual safety and reducing risky behaviors.	Extent to which cyclists give space to other cyclists Motives for obeying or not obeying traffic rules	Hassen et al. (2011); Hukker & Vissers (2023); Kummeneje & Rundmo (2020); Rissel et al. (2002); Twisk et al. (2015); Useche et al. (2021); Wang et al. (2020)

2.4.1. Decision-making at intersections

Decision-making at intersections (DMI) involves a cyclist's ability to make decisions in preparing, planning, and carrying out cycling tasks at intersections by applying traffic rules (Hukker & Vissers, 2023). The importance of fluently applying rules at intersections, and its inclusion in the WEVER test suite, is supported by prior research. In a study by Schaefer et al. (2008), results showed that children tend to prioritize motor over cognitive functions when a task involves both. Such prioritization has direct implications for a child's safety while cycling, as it increases the risk of injury in traffic situations (Schaefer et al., 2008). More specifically, as children focus on the physical act of cycling, they may neglect cognitive tasks, such as determining which user has the right-of-way, which could lead to dangerous situations. This can, in turn, increase the risk of young cyclists being involved in accidents at intersections (Liikenneturva, 2023). Barton and Morrongiello (2011) further state that the cognitive processing and attention needed to cross a road are only fully developed in the later years of primary school.

2.4.2. Hazard perception as part of situational awareness

Hazard perception is part of the broader construct of situational awareness (SA). Endsley (1995) defines SA as “the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future” (p. 36). Endsley (1995) further elaborates that SA includes perception and comprehension, with the latter being dependent on the former.

In the context of traffic safety, hazard perception refers to a cyclist’s ability to identify and anticipate potential dangers on the road before they become immediate threats (Crundall et al., 2012). This skill is considered crucial for safe cycling, as it enables cyclists to respond proactively to changing traffic situations.

The process begins with first detecting salient elements in the environment, allowing cyclists to perceive risks. For example, changes in road conditions, traffic, visibility, weather, and the behavior of other road users (Hukker & Vissers, 2023). With comprehension, cyclists can recognize and understand these risks and assess their impact to adjust their cycling behavior in a timely manner (Hukker & Vissers, 2023).

According to a study by Oron-Gilad et al. (2011), children under the age of thirteen have a longer latency in identifying and responding to traffic situations compared to adults. Furthermore, a study by Crundall et al. (2012) found that experienced drivers can recognize hazard-related cues faster and more easily than less experienced drivers. Hill et al. (2000) found that young children struggle to recognize risky situations, perhaps due to age or a lack of experience. Additionally, Twisk et al. (2018) identified predictors for crash involvement, including skill level, behavior, and HP. As identified by Endsley (1995), individuals who lack perception will have their comprehension of the traffic situation impacted.

2.4.3. Gap acceptance as part of risk acceptance

Gap acceptance is measured as part of risk acceptance. Gap acceptance refers to a cyclist’s ability to judge whether a gap in traffic is large enough to safely enter, cross, or merge into a traffic stream. The skill of choosing and accepting gaps is particularly relevant at intersections and roundabouts, where conflicts and delays frequently arise during the movements of vehicles or persons (Bath & Shah, 2022).

Research has found that while children’s road-crossing behavior is like that of adults, they leave less headway when they start a crossing (Chihak et al., 2010). Consequently, children end up with far less amount of time to spare to clear the path before an oncoming car. This puts children at a greater risk for collision because they have less time available to recover from an error such as a foot slipping off the pedal (Chihak et al., 2010; Plumert et al., 2004).

Gap acceptance builds upon other the other HOCS. As an example, a young cyclist may identify and understand the risk of an oncoming car, thereby using their skills related to hazard perception. They might evaluate that a car 100 meters away provides a much higher safety margin for crossing than a car 10 meters away. Hence, gap acceptance within the WEVER project is defined as the ability to use knowledge and skills related to anticipating potential hazards on the road, allowing cyclists to effectively and safely navigate various traffic situations by implementing preventive measures (Hukker & Vissers, 2023).

2.4.4. Morally acceptable cycling behavior

Finally, the last HOCS in the WEVER project is the readiness to show morally acceptable cycling behavior (MACB). This skill first relates to the behavior a cyclist exhibits in relation to traffic rules (Roelofs et al., 2019). A cyclist who commits numerous errors and violations of traffic rules is considered to have low MACB and thus exhibit risky behavior, which could be due to poor knowledge of traffic regulations (Hassen et al., 2011). A lack of knowledge of traffic regulations also appears to be linked to negative attitudes toward other road users (Rissel et al., 2002).

Secondly, MACB refers to the extent to which a cyclist empathizes with other road users. For example, a cyclist who leaves very little space behind other cyclists exhibits low MACB, and cyclists who engage in positive cycling attitudes are more likely to ensure the mutual safety of other road users and exhibit high MACB (Roelofs et al., 2019) Lastly, MACB also encapsulates the extent to which risky behavior is justified (Roelofs et al., 2019). For instance, a cyclist who suddenly swerves on the road because another road user did not see them, exhibits more justified risky behavior than a cyclist who does the same, to annoy people behind them.

Risky behavior has been shown to increase the likeliness of collision involvement (Twisk et al., 2015; Useche et al., 2021). In a study by Kummeneje and Rundmo (2020), attitudes toward traffic rule violations and safety priorities predicted the frequency of rule violations. Simultaneously, attitudes toward rule enforcement and dissatisfaction with traffic rules were predictors of conflicts with other road users which enhanced the risk of collision involvement (Kummeneje & Rundmo, 2020).

2.5. Research questions

Data within the WEVER project was collected across four different years. This thesis aims to (1) provide an overview of bike use and cycling safety, (2) examine the demonstration of higher-order cycling skills (HOCS), (3) investigate the perceived quality of both informal and formal traffic education and the demonstration of HOCS, and (4), explore the extent to which HOCS, informal and formal traffic education, and other relevant variables predict cycling safety outcomes. The following research questions were central to this study:

1. How frequently do young cyclists aged 11 to 13 in the Netherlands use their bicycles, and how often are they involved in cycling collisions across years and provinces?
2. To what extent do cyclists demonstrate higher-order cycling skills across years and provinces in the Netherlands?
3. To what extent is the perceived quality of formal and informal traffic education related to the performance of higher-order cycling skills?
4. To what extent can cycling safety outcomes be explained by the quality of traffic education received and by the level of demonstrated higher-order cycling skill, when controlling for student characteristics, bike use, and provincial and temporal variations?

3. Methods

3.1. Research design

This thesis uses a cross-sectional research design to investigate higher-order cycling skills (HOCS) in children aged 11 to 13 in the Netherlands using data collected from the WEVER test suites in 2017, 2019, 2020, and 2022. However, due to incomplete data in the 2017 and 2019 datasets, only data from 2020 and 2022 were included in the analysis of this thesis.

The thesis follows the logic of the research question. The first two research questions adopt a descriptive research design. Bike use, collision involvement, and the demonstration of each HOCS across provinces and years in the Netherlands are described. The subsequent two research questions take an explanatory approach. More specifically, predictive models for the HOCS using traffic education at school and traffic education at home as measures of formal and informal traffic education, respectively, along with student characteristics. Additionally, predictive models for collision involvement were developed using HOCS and traffic education at school and home, while controlling for student characteristics and bike use.

3.2. Respondents

3.2.1. Sampling method

A convenience sampling approach was used to select schools across the Netherlands. More specifically IPO representatives from each province aimed to select schools with diverse student characteristics (e.g., demographics, academic for secondary education follow-up track), school denomination (e.g., public, religious denomination), and location (e.g., urban/rural). Once schools were selected, the schools were contacted by the IPO representative and asked to participate in the study. Participation by the schools was entirely voluntary.

3.2.2. Provinces, participating schools, and participants

The dataset included 117 schools from 6 provinces, 38 schools participated in 2020, and 79 schools participated in 2022. The included provinces across years were Drenthe (70 schools: 22 in 2020 and 48 in 2022), Flevoland (7 schools in 2022), Groningen (26 schools: 4 in 2020 and 22 in 2022), North Holland (10 schools: 2 in 2020 and 8 in 2022), South Holland (13 schools: 10 in 2020 and 3 in 2022), and Zeeland (3 schools in 2022).

In total there was a sample of *n* = 2267 participants, 827 participants in 2020 and 1440 participants in 2022. The gender distribution was 52.7% females (*n* = 1195). However, not all participants completed all subtests in the WEVER test suite, which explains the variation in the number of cases available or the background variables reported.

Academic advice refers to the recommendation given to a student regarding the most suitable secondary education track. This advice is based on an assessment by the classroom teacher and the results of a compulsory national test, administered halfway through grade 6 (ages 9–10). The test evaluates reading, math, attitude toward learning, interests, and motivation. Based on both the teacher's assessment and the test results, each student is given a recommended educational level. These are: (1) preparatory secondary vocational education (Vmbo), (2) Vmbo- junior general secondary education (MAVO), (3) senior, general secondary education (HAVO), (4) HAVO-Pre-University education, and (5) Pre-University education, with Vmbo being the lowest academic track and Pre-University the highest.

For academic advice, data was collected from 2267 participants. The largest percentage of academic advice was directed toward Vmbo, representing 37.8% (*n* = 857). 15.1% (*n* = 343) was accounted by MAVO, 19.8% (*n* = 448) for HAVO, 14.7% (*n* = 334) for HAVO-Pre-University education, and 12.6% (*n* = 285) for Pre-University education.

3.3. Data collection

The WEVER test suite was administered online using a laptop computer, desktop computer, or tablet. It contained six subtests and took around 45 minutes to complete. Four of the subtests assessed the HOCS: decision-making at intersections, hazard perception, gap acceptance, and morally acceptable cycling behavior. For the fifth subtest, data were gathered about student characteristics, including gender, age, and academic advice, as well as data on bike use, involvement in collisions, and evaluation of traffic education at home and at school. The sixth subtest was an evaluative questionnaire of the user's experience with the WEVER test suite.

For this thesis, the data of the evaluative questionnaire were not analyzed as it did not fall under the scope of this study. Table 2 summarizes the content of the various subtests of the test suite, and a detailed description of each subtest is provided in sections 3.3.1 to 3.3.7.

Table 2

Summary of subtests, including the number and sample of test items, response type, and the maximum possible score

Subtest	# of items	Sample item	Response type	Max test score	Coding key
Decision-making at intersections	11	See Figure 1	Mouse click	11	Priority is correct (1) / not correct (0)
Hazard perception	16	See Figure 2	Key pressed and response time	16	Hazard detected (1) / not detected (0)
Gap acceptance	20	See Figure 4	Key pressed and response time	20	Crossing is safe (1) / not safe (0)
Morally acceptable cycling behavior	10	See Figure 5	11-point scale (0 to 10)	100	Cumulative score
Student characteristics	3	What is your age? What is your gender? What is your given education advice?	Filled out number / 4-point Likert scale	/	/
Bike use	7	Number of rides per week with the bicycle	3-point Likert scale (0, 1, 2 times per day)	14	Cumulative score
Formal and informal traffic education	4	Have you talked to your parents or guardians about the best time to cross?	3-point Likert scale	100	Cumulative score
Near collisions, collisions, and doctor's visits	3	Have you collided with something by bike in the past year?	4-point Likert scale	1	Involvement (1) / no involvement (0)

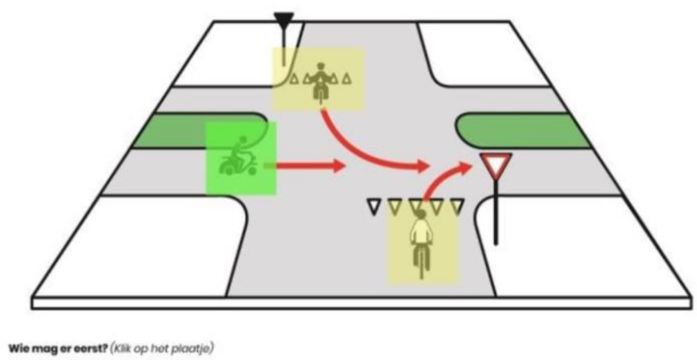
3.3.1. Decision-making at intersections

The subtest for decision-making at intersections was assessed through eleven items. More specifically, participants' knowledge of traffic rules and their ability to decide about the order to go at intersections, were evaluated. The tasks highlighted the importance of decision-making at intersections, and quick and accurate thinking to adhere to traffic rules to avoid potential risks and collisions. This subtest used schematic illustrations, with participants in the perspective of a cyclist in a real-life situation.

In these tasks, participants were presented with a situation involving road users, including pedestrians, cyclists, and other vehicles, at an intersection. Based on the situations, participants had to respond to the item "Who gets to go first?" by determining which user had the right-of-way. Participants responded to the items by clicking with a mouse on the road users. A score of 1 was awarded for each correctly identified order of precedence, and 0 points were given for an incorrect sequence. The items varied in complexity depending on the number of road users each scenario included. Scenarios included between two and four users. Additionally, the situations were depicted in a way where the participant was a cyclist themselves and might or might not have priority, therefore adding an additional layer of decision-making. Figure 1 provides an example item of the DMI subtest. Cronbach's alpha for this subtest was $\alpha = .61$ in 2020 and $\alpha = .65$ in 2022.

Figure 1

Example item of the decision-making at intersections subtest



Note. From Hukker and Vissers (2023).

3.3.2. Hazard perception

In 2020 and 2022, the hazard perception subtest demonstrated good consistency, with Cronbach's alpha values of .71 and .8, respectively. The subtest of hazard perception consisted of sixteen items. Participants were tested on their ability to anticipate how a traffic situation might develop by identifying and recognizing early signs of danger, essential for safe cycling. More specifically, participants were asked to indicate changes in salient elements of the road or the behavior of other road users.

In each item, a brief video clip from a cyclist's viewpoint, which simulated a real-life cycling trip, was presented to the test-taker. Figure 2 presents an example of an item. During the clip, test-takers were expected to press the spacebar whenever they perceived a potential hazard emerging in the video clips and to do so as quickly as possible. The hazards in the videos never materialized, ensuring the tasks focused on participants' ability to anticipate danger by perceiving and understanding the risk, as opposed to reacting to the danger.

Figure 2

Example item of the hazard perception subtest

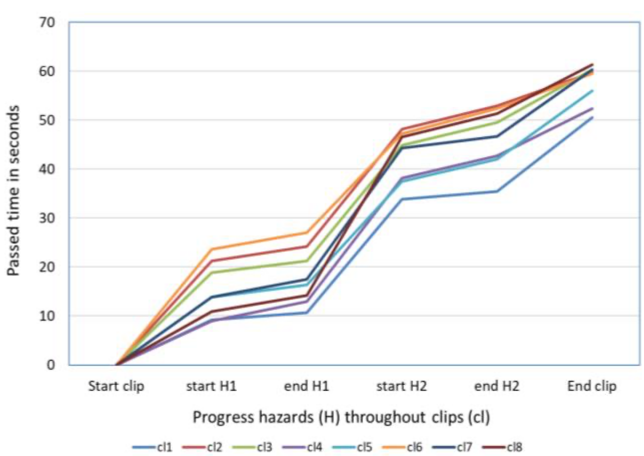
Note. From Hukker and Vissers (2023).

Within each clip, two hazards needed to be identified, within a set timeframe. This timeframe, considered correct, was on average 3.6 seconds (*SD* = 1.3 seconds). The hazards were distributed across the clip as represented in Figure 3. The clips lasted on average 57.5 seconds (*SD* = 4.1 seconds), allowing for variation in item complexity. In addition, participants' reaction times were recorded from the moment a hazard was presented until a participant responded. The responses of each item were scored 0 in case of a missed hazard and 1 for a correctly timed and noted hazard.

As test-takers had to click whenever they perceived a risk, results showed that some participants clicked many times throughout the clips. Because of this, participants who gave more than six responses before a hazard appeared on nine or more items, were not included in the subtest analysis. Participants were also removed from the analysis if they gave no responses on nine or more tasks.

Figure 3

Starting and ending moments of hazards throughout test clips



3.3.3. Gap acceptance

The subtest on gap acceptance aimed to assess participants' ability to evaluate whether it would be safe for them to cross a road. This subtest included a total of seven task scenarios composed of brief, real-life situation videos from the perspective of a cyclist waiting at an intersection to cross.

In the gap acceptance subtest, test takers were presented with seven crossing scenarios at a variety of intersections, where a stream of different vehicles passed (i.e., cars, trucks, mopeds, etc.). Immediately after a road user had passed and before its pursuer, participants were instructed to determine if the gap between the two road users was safe enough to cross. The test taker responded to the item as soon as they heard a bell and the text that appeared on the screen stating, "Choose now." Figure 4 provides an example of such a gap. The arrow in the graphic was not shown to test takers but was used here to illustrate an example of a gap to be assessed.

For each scenario, test-takers evaluated 2 or 3 gaps. The duration of the gap was measured as the time elapsed between the moment the rear end of the first road user vehicle had passed a specific point and the moment the extreme front end of the next road user had reached the same point. The gap lengths ranged from 1.8 to 7.2 seconds. In the shortened version of the test, participants assessed a total of 20 gaps.

The scores assigned to each response were 1 when participants correctly identified a gap that was safe to cross, while a score of 0 was given if the gap was too short and therefore considered dangerous. Test-takers were not limited in the number of responses they could give for each gap. Therefore, it was decided that data from students who had clicked more than six times per gap for more than six gaps were excluded from the analyses. Nevertheless, the gap acceptance test received an acceptable reliability score across all years. In 2020 and 2022, the Cronbach scores were α = 0.77 and 0.79, respectively.

Figure 4

Example item of the gap acceptance subtest

Note. From Hukker and Vissers (2023).

3.3.4. Morally acceptable cycling behavior

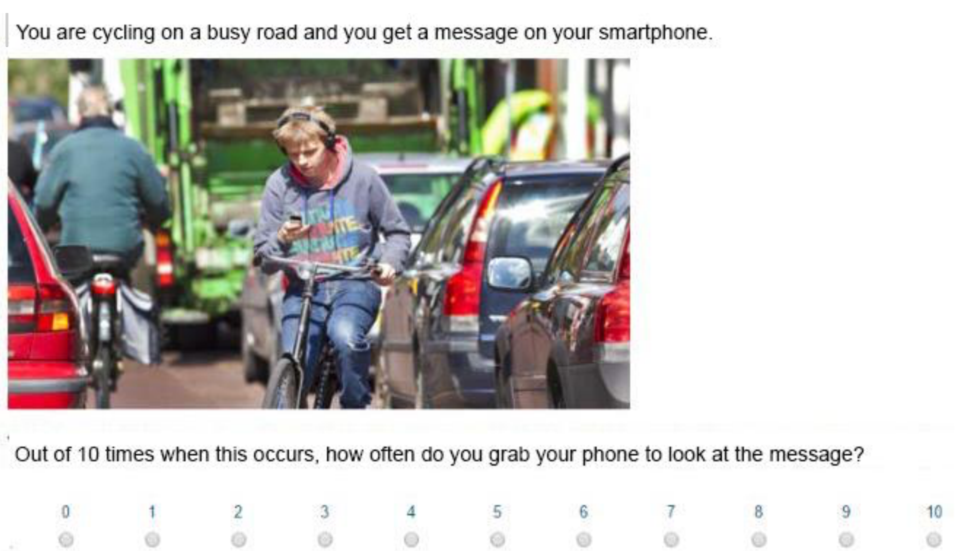
This subtest assessed the higher-order cycling skill related to children's readiness to demonstrate morally acceptable cycling behavior. Participants were presented with ten items, each containing a different traffic scenario in which they shared traffic space with other road users. This format encouraged self-reflection on their cycling behavior and its consequences for others. The items focused on measuring empathy, moral decision-making, and the extent to which they refrained from self-centered and socially undesirable actions in traffic, which, as a result, could cause harm to other cyclists.

These scenarios required participants to choose between prioritizing their own interests and considering the needs of others in traffic. In some scenarios, the other road users were directly present, while in others, they were indirectly present. Through these scenarios, the aim of this subtest was to evaluate the extent to which the test takers committed to self-centered decisions in traffic. The scenarios depicted common violations of traffic rules, where following one's own interest could potentially cause harm to others.

The score on the test is the mean score across all 10 items, representing the average number of times a non-desirable behavioral option (as depicted in Figure 5) was chosen. In 2020 and 2022, Cronbach's alpha was $\alpha = 0.81$ for both years, suggesting good reliability. For interpretation purposes, the scale for morally acceptable cycling behavior was reversed. Hence, the score related to MACB represents the number of times participants chose not to commit a violation or to perpetrate a social norm in presented traffic situations, thus acceptable cycling behavior.

Figure 5

Example item of the subtest morally acceptable cycling behavior



Note. From Buijs et al. (2017).

3.3.5. Student characteristics and bike use

Student characteristics include items related to participants' demographics (age and gender), academic advice, and bike use. School identifiers, provinces, and years were gathered automatically. Academic advice which refers to the recommendation given to a student regarding the most suitable secondary education track for them was categorized into five educational levels. These levels are: (1) preparatory secondary vocational education (Vmbo), (2) Vmbo- junior general secondary education (MAVO), (3) senior, general secondary education (HAVO), (4) HAVO-Pre-University education, and (5) Pre-University education.

Regarding bike use, the WEVER subtest included items that asked on which days students used their bikes, and for how many rides per day they used them. They responded to a 3-point scale: "Not cycling" (0 points), "Cycling once" (1 point) and "Cycling more than once" (2 points). It is recognized that this range was restricted, due to students who might have made more than 3 rides. The scores were combined to form a total estimated cycling frequency ranging from 0 to 14.

3.3.6. Formal and informal traffic education

Formal and informal traffic education was measured by asking questions about traffic education at school and at home. Items evaluated students' perceived experience of these two types of education for each higher-order cycling skill, specifically focusing on the extent to which they were prepared by their school or parents/guardians.

For each HOCS, three questions were included. As an example, for hazard perception: (1) "Hazards – I talked with parents or guardians about watching out for dangers in traffic", (2) "Hazards – I practiced with the school in traffic, watching out for dangers in traffic", and (3) "Hazards – I was taught in class about watching out for hazards in traffic." Hence, for each HOCS, two items measured traffic education at school, and one item measured traffic education at home. Responses were recorded on a 3-point Likert scale: "No, (almost) never", "Yes, sometimes", and "Yes, often". To generate overall scores, school-based and home-based traffic education responses were re-coded, summed, and transformed into two overall scores for the experienced quality of informal traffic education at home and formal traffic education at school, both ranging from 0 to 100.

3.3.7. Collision involvement

Cycling safety outcomes were measured using three items assessing incidents involving objects, other individuals, or oneself. Responses were recorded on a four-point Likert scale: "No", "Yes, almost", "Yes, once", and "Yes, several times". Example items included: "Have you collided with something while cycling in the past year?”. For analyses, only collisions were analyzed. Collision involvement was classified as a dichotomous variable by combining “Yes, once” and “Yes, several times.”. The third item assessed whether participants required medical attention due to a cycling-related accident, with ‘No”, “Yes, once”, and “Yes, several times”. “Yes, once”, and “Yes, several times” were combined for analysis and dichotomized.

3.4. Procedure

3.4.1. Data collection process

The procedure for collecting data in 2020 and 2022 relied on provincial employees, referred to in this context as coordinators, were responsible for selecting schools (Tsapi et al., 2021; Tsapi et al., 2022). Furthermore, digital links to the test platforms were shared, and teachers at the participating schools who were responsible for administering the tests, ensuring the students had access to their personal test link. The teachers were also in charge of supervising the students.

3.4.2. Ethical considerations

After schools agreed to take part in the research, letters were sent to parents informing them about the data collection that would take place (Twisk et al., 2017; Tsapi et al., 2021; Tsapi et al., 2022). Parents had one week to inform the school if they did not want their child to partake in the data collection.

On the day of data collection in the schools, the children were informed about the WEVER tests: the purpose and the procedure of the test, as well as their rights as participants. The students were assigned a subject number to ensure anonymity. Their results, however, could be traced back to the school where the tests were taken (Twisk et al., 2017; Tsapi et al., 2021; Tsapi et al., 2022).

3.5. Data analysis

3.5.1. Research question 1: Bicycle use and cycling safety

The aim was to examine descriptive analysis for bicycle use and cycling safety across years and provinces. For bicycle use and collision involvement, data were collected from n = 2267 participants. To examine differences in bicycle use, two-way ANOVAs were conducted with years and provinces as independent variables, including their interaction, and cycling use as the dependent variable. For the interaction term, the included provinces were Drenthe, Groningen, North Holland, and South Holland, as these were the only provinces with data available across the years. For safety outcomes, logistic regression models were built to investigate year, provinces, and their interaction as independent variables on the dependent variable (collision involvement).

3.5.2. Research question 2: Demonstration of higher-order cycling skills

This research question aimed to examine the extent to which participants demonstrated higher-order cycling skills across years and provinces in the Netherlands. Descriptive analysis involved computing the means, standard deviations, and the proportion of children meeting each established HOCS standard. To test for differences between provinces and years, separate two-way ANOVAs were conducted for each HOCS, including their interaction. The dependent variables were the scores of the HOCS, and year and province were the independent variables.

3.5.3. Research question 3: Traffic education as a predictor of higher-order cycling skills

The objective of this analysis was to develop multiple regression models to examine the extent to which the demonstration of each higher-order cycling skill (HOCS) as the dependent variables could be predicted by the independent variables including formal and informal traffic education, controlling for other student characteristics (gender, age, bike use, and academic advice). Only independent variables that were statistically significant or theoretically justified were retained in the model. Consequently, four regression coefficient models were constructed to provide directional estimates for each predictor and assess their individual effects on HOCS and the adjusted R^2 was provided to evaluate the fit of each model.

3.5.4. Research question 4: Traffic education and higher-order cycling skills as predictors of cycling safety

This research question aimed to predict participants' safety outcomes. To achieve this, logistic regression models were built with collision involvement as the dependent variables. The independent variables included the four higher-order cycling skills (HOCS), student characteristics (gender, age, and academic advice), bicycle use, formal and informal traffic education, province, and year. Only statistically significant predictors were retained in the final model.

The model fit was assessed using the Hosmer-Lemeshow goodness-of-fit test. In addition, the estimated coefficients for each predictor were analyzed, and the practical effect of each significant predictor on safety outcomes was calculated to interpret their influence on cycling safety outcomes.

4. Results

The results of the analyses are presented in the order of the research question posed.

4.1. Research question 1: Bicycle use and cycling safety

4.1.1. Bicycle use

Table 3 displays the total bike use across years and provinces. On a scale from 0 to 14, the overall mean was 8.02 (*SD* = 4.2), representing riding 8 times throughout the week. A two-way ANOVA was conducted to investigate the effect of years and provinces on cycling use. Results showed a significant interaction between years and provinces on bike use, $F(3, 2105) = 11.72$, $p < .001$, with a negligible effect size ($\eta^2 = 0.02$). Nevertheless, this suggests patterns of bike use varied across years and provinces. Figure 6 presents the mean bicycle use across years and provinces.

Table 3

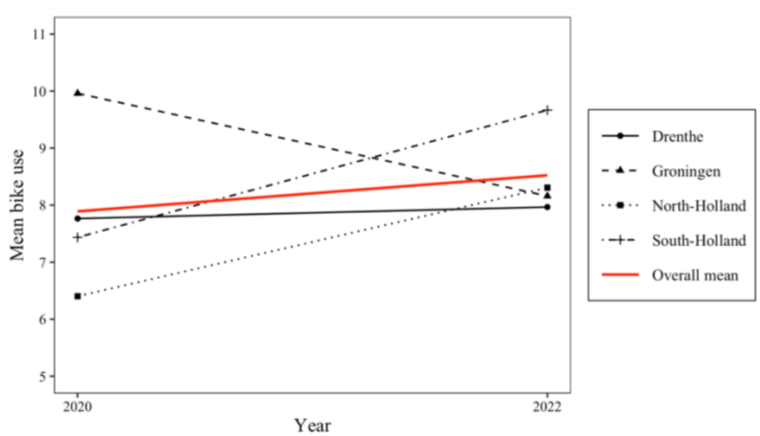
Frequency of bike use across years

Year	*n*	*M**	*SD*
2020	827	7.76	4.3
2022	1440	8.17	4.14
Total	2267	8.02	4.2

Note. * Scale: 0 to 14.

Figure 6

Mean bicycle use across provinces and years



Note. The original scale is from 0 to 14, however, a restricted range is shown to enhance visual clarity.

4.1.2. Involvement in collisions

The proportion of grade 6 primary school students who reported being involved in collisions with either objects or others across 2020 and 2022 was 0.37 (*n* = 991 of 2650). More specifically, the proportion of collision involvement in 2020 was 0.4 (n = 331 of 827) and in 2022 it was 0.36 (n = 660 of 1823).

A logistic regression was conducted to examine the effects of year and provinces on the likelihood of collision involvement. After controlling for provinces, the odds of being involved in a collision were significantly higher in 2022 compared to 2020, $B = 0.33$, $SE = 0.12$, $p = .006$, indicating that year was a significant predictor.

4.2. Research question 2: Demonstration of higher-order cycling skills

4.2.1. Decision-making at intersections

Table 4 shows the levels of performance for decision-making at intersections (DMI). The mean score was 5.99 (n = 2267, SD = 2.39), on a scale of 0 to 11. A two-way ANOVA was performed to examine differences in mean DMI scores across years and provinces. The interaction term between year and provinces on DMI scores was significant, $F(3, 2257) = 10.08$, $p < .001$, with a very small effect size ($\eta^2 = 0.01$). This indicates that DMI scores across years and provinces fluctuated. Figure 7 displays the mean DMI scores across years and provinces.

Table 4

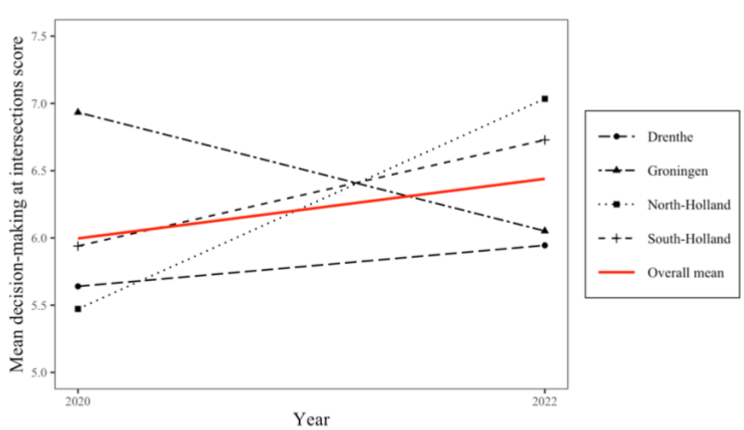
Level of performance in decision-making at intersections subtest across years

Year	*n*	*M**	*SD*
2020	827	5.82	2.32
2022	1440	6.09	2.42
Total	2267	5.99	2.39

Note. * Scale: 0 to 11.

Figure 7

Mean scores of decision-making at intersections across years and provinces



Note. The original scale is from 0 to 11, however, a restricted range is shown to enhance visual clarity.

The standard for an acceptable level for DMI was considered accomplished if at least 7 of 11 items were responded correctly. Across 2020 and 2022, the proportion of participants meeting the standard was 0.4 (n = 902 of 2267). In 2020, the standard was met by 0.37 (n = 309 of 827), and in 2022, it was met by 0.41 (n = 593 of 1440).

4.2.2. Hazard perception

Table 5 displays the demonstrated performance for hazard perception (HP) across years. The overall mean score was 8.22 (*SD* = 3.52), on a scale between 0 and 16. A two-way ANOVA showed a significant main effect of year on HP scores, $F(1, 1294) = 57.53$, $p < .001$, indicating differences across years, however, with a very small effect size ($\eta^2 = 0.04$). Across the years, a downward trend was observed, from 8.9 (*SD* = 3.23) in 2020 to 7.36 (*SD* = 3.76) in 2022. In addition, the main effect of provinces on HP scores was also significant, $F(5, 1294) = 2.43$, $p = .03$, indicating differences across provinces, with a negligible effect size ($\eta^2 = 0.009$). Zeeland scores the lowest (*M* = 6.6, *SD* = 3.48) while South Holland scored the highest (*M* = 9.19, *SD* = 3.59). The interaction between year and provinces on HP scores were not significant.

Table 5

Level of performance for the hazard perception subtest across years

Year	*n*	*M**	*SD*
2020	695	8.90	3.23
2022	609	7.45	3.69
Total	1524	8.36	3.46

Note. * Scale: 0 to 16.

The standard for an acceptable level of hazard perception was reached if 10 correct responses out of 16 items were given. This threshold was met by .39 (n = 505 of 1304) of participants. The proportion of children reaching this competency in 2020 was 0.46 (n = 317 of 695) and in 2022, it was 0.31 (n = 188 of 609).

4.2.3. Gap acceptance

Table 6 displays the number of gaps accepted when crossing a street across, on a scale ranging between 0 and 20. Lower scores show safer crossing distance Across the data, the mean score for this subtest was 5.53 (*SD* = 3.2). A two-way ANOVA investigating the difference in mean scores across years and provinces revealed a significant main effect for provinces, $F(5, 2047) = 4.38$, $p < .001$, however, with a small effect size ($\eta^2 = 0.01$). This demonstrates significant differences among scores of gap acceptance across provinces in the Netherlands. Drenthe scored the lowest (*M* = 5.29, *SD* = 3.13), demonstrating children crossed the road with safer distances between oncoming traffic, while Zeeland had the highest scores (*M* = 6.76, *SD* = 3.67), suggesting children crossed the roads with less time.

Table 6

Number of gaps accepted when crossing a street across years

Year	*n*	*M**	*SD*
2020	744	5.70	3.33
2022	1313	5.43	3.13
Total	2057	5.53	3.2

Note. * Scale: 0 to 20.

Furthermore, the standard for gap acceptance was met if participants only chose gaps that had at least 4.5 seconds of clearance time or scored lower than 5. Across 2020 and 2022, the proportion of children that met this standard was 0.56 (*n* = 1162 of 2057). More specifically, in 2020, the proportion of children to reach this standard was 0.54 (*n* = 403 of 744) and in 2022, the proportion was 0.58 (*n* = 759 of 1313).

4.2.4. Morally acceptable cycling behavior

The overall mean score morally for acceptable cycling behavior (MACB) was 7.58 (*SD* = 1.66), with scores ranging between 0 and 10. A two-way ANOVA was conducted to examine MACB scores across years and provinces. Results showed a significant main effect for provinces, $F(5, 1639) = 7.48$, $p < .001$. Among provinces, Zeeland had the highest mean (*M* = 8.15, *SD* = 1.56), while Flevoland, had the lowest (*M* = 6.77, *SD* = 1.96). Nevertheless, the effect size remained small ($\eta^2 = 0.02$). There was no significant main effect for years on the MACB scores.

Table 7

Number of times students refrained from traffic violations across years

Year	*n*	*M**	*SD*
2020	827	7.69	1.64
2022	822	7.46	1.67
Total	1649	7.9	1.66

Note. * Scale: 0 to 10.

The standard for MACB was achieved if children refrained from traffic violations at least 8 out of 10 times. Based on this set cut-off, 0.48 (*n* = 797 of 1649) of participants met the standard. In 2020, the proportion of participants that met this standard was 0.5 (n = 413 of 827) and in 2022, the proportion was 0.47 (n = 384 of 822).

4.3 Research question 3: Relation between traffic education and higher-order cycling skills

4.3.1. Experienced traffic education at school and at home

Tables 8 and 9 presents students' overall experienced traffic education at school and at home, respectively, across years, on a scale between 0 to 100. For education at school, the mean score was 46.62 (*SD* = 22.71) and for the education at home, the mean score was 39.69 (*SD* = 27.91).

Table 8

Experienced quality of traffic education at school across years

Year	*n*	*M**	*SD*
2020	827	45.1	21.7
2022	1440	47.5	23.2
Total	2267	46.62	22.71

Note. * Scale: 0 to 100. The scale was a linear transformation from the original 3-point Likert scales, for the composing questions.

Table 9

Experienced quality of traffic education at home across years

Year	*n*	*M**	*SD*
2020	827	41.3	27.3
2022	824	38.1	28.4
Total	1651	36.69	27.91

* *Note*. Scale: 0 to 100.

Two-way ANOVA to examine the effects of years and provinces on traffic education at school showed a significant main effect of year, $F(1, 2257) = 6.27$, $p = .01$, and a significant main effect of province, $F(5, 2257) = 24.09$, $p < .001$. The interaction between year and province was not significant.

The mean perceived traffic education at school scores increased slightly in 2020 to 2022. Across provinces, North Holland had the lowest mean score ($M = 39.3$, $SD = 22.67$), while Zeeland the highest ($M = 58.2$, $SD = 27.7$). However, the effect size of both year and provinces on education at school was found to be small ($\eta^2 = .003$ and $\eta^2 = .05$, respectively).

A two-way ANOVA tested the effects of year and province on the score of education at home. Similarly to education at school, the main effect of year was significant on education at home, $F(1, 1641) = 5.44$, $p = .02$, however, with a negligible effect size ($\eta^2 = .003$). In general, a decreased trend of education at home was observed.

The main effect of provinces on education at home was also significant, $F(5, 1641) = 4.88$, $p < .001$, nevertheless, the effect size was negligible ($\eta^2 = .01$). Groningen had the highest mean ($M = 47$, $SD = 27.1$), while Drenthe the lowest ($M = 37.5$, $SD = 27.3$). The interaction between year and province on education at home was not significant.

4.3.2. Impact of traffic education on decision-making at intersections

The multiple regression model predicting decision-making at intersections was significant, $F(3, 1647) = 69.75$, $p < .001$, and explained 11.11% of the variance in DMI scores, with a residual standard error of 2.27 on 1647 degrees of freedom. Table 10 provides the regression coefficients for each predictor. Academic advice and traffic education at home were found to be significant predictors of DMI scores and education at school was found to be a marginally significant predictor of DMI.

Table 10

Regression coefficients for predicting the scores of the decision-making at intersections subtest

Predictors	*B*	Standard error	*t*-value	*p*-value
Intercept	4.57	0.17	26.94	< .001***
Academic advice	0.55	0.04	14.33	< .001***
Traffic education at home	-0.004	0.002	-2.06	0.04**
Traffic education at school	0.005	0.003	1.71	0.09*

*** indicates $p < .001$, ** indicates $p < .05$, * indicates $p < 0.1$.

4.3.3. Impact of traffic education on hazard perception

The multiple linear regression model predicting hazard perception was significant $F(1, 1302) = 11.06$, $p < .001$, with a residual standard error of 3.51 on 1302 degrees of freedom, explaining 0.76% of the variance in HP scores. Table 11 presents the regression coefficient for the included predictors. No significant effects were found for education at home and at school, bike use, age, and gender on the performance of the DMI subtest.

Table 11

Regression coefficients for predicting the scores of the hazard perception subtest

Predictors	*B*	Standard error	*t*-value	*p*-value
Intercept	7.66	0.19	39.35	< .001***
Academic advice	0.22	0.07	3.33	< .001***

*** indicates $p < .001$.

4.3.4. Impact of traffic education on gap acceptance

The multiple regression model for predicting gap acceptance was not significant, $F(2, 2054) = 2.49$, $p < .08$, with a residual standard error of 3.2 on 2054 degrees of freedom. The model explained less than 0.01% of the variance in gap acceptance scores, indicating a very weak explanatory power. Table 12 presents the regression coefficients of the model.

Table 12

Regression coefficient for predicting the performance of gap acceptance

Predictors	*B*	Standard error	*t*-value	*p*-value
Intercept	5.74	0.21	28	< .001***
Academic advice	0.04	0.05	0.77	0.44
Traffic education at school	-0.007	0.003	-2.09	0.04**

*** indicates $p < .001$, ** indicates $p < .05$.

4.3.5. Impact of traffic education on morally acceptable cycling behavior

The multiple regression model for predicting morally acceptable cycling behavior was significant, $F(5, 1643) = 33.43$, $p < .001$, with a residual standard error of 1.59 on 1643 degrees of freedom. The model explained 8.96% of the variance in MACB scores. The regression coefficients for each predictor in the model are presented in table 13. Gender, academic advice, and traffic education both at home and at school, were found to be significant. On the other hand, age and bike use were not found to be significant predictors for the performance for the subtest of MACB.

Table 13

Regression coefficients for predicting the scores of the morally acceptable cycling behavior subtest

Predictors	*B*	Standard error	*t*-value	*p*-value
Intercept	7.17	0.14	50.41	< 0.001 ***
Gender (Female = 1)	0.48	0.08	6.29	< 0.001 ***
Academic advice	0.09	0.03	3.43	< 0.001 ***
Bike use	-0.04	0.01	-4.82	< 0.001 ***
Traffic education at school	-0.005	0.002	-2.88	0.004 **
Traffic education at home	0.01	0.001	8.843	< 0.001 ***

*** indicates $p < .001$, ** indicates $p < .01$.

4.4. Research question 4: Traffic education and higher-order cycling skills as predictors of cycling safety

Logistic regression models were applied to predict safety outcomes (collision involvement) using the four higher-order cycling skills: decision-making at intersections, hazard perception, gap acceptance, and morally acceptable cycling behavior, and traffic education at school and at home, while controlling for student characteristics, bike use, provinces, and years.

The logistic regression model for involvement in collisions (AIC = 2130.26) performed much better than the null model (AIC = 4660.1), despite the small improvement in classification accuracy (full model: 64.16%; null model: 61.95%). While classification accuracy offers a direct measure of performance, AIC provides a more comprehensive evaluation by accounting for both model fit and complexity.

Table 14 displays the result of the logistic regression model. Significant predictors of collision involvement included two HOCS: scores of decision-making at intersections and morally acceptable cycling behavior, as well as traffic education at school and at home and bike intensity. To calculate the percentage change in odds of collisions, the coefficients from the logistic regression were first exponentiated to obtain the odds ratios (OR), using the formula $OR=e^{B}$. The percentage change was then derived using (1−OR)×100 when OR < 1 (indicating a decrease in odds), and (OR−1)×100, when OR > 1 (indicating an increase).

A one-unit increase in DMI resulted in a 6.46% decrease in odds of collisions (OR = 0.94, 95% CI: [0.9, 0.98]), and a one-unit increase in MACB scores resulted in a 24.22% decrease in odds of collisions (OR = 0.76, 95% CI: [0.71, 0.81]). Traffic education at school and at home had opposite effects, with a one-point increase in traffic education at school increased the odds of collision involvement by 0.57% (OR = 1.01, 95% CI: [1.00, 1.01]), whereas a one-point increase in traffic education at home lowered the odds of collisions 0.56% (OR = 0.99, 95% CI: [0.99, 1.00]). For every additional bike ride recorded, it resulted in a 5.12% increase in the odds of collisions (OR = 1.05, 95% CI: [1.03, 1.08]).

Table 14

Regression coefficient for predicting involvement in collisions while cycling

Predictors	*B*	Standard error	*z*-value	*p-value*
Intercept	1.76	0.31	5.61	< .001 ***
Decision-making at intersections	-0.07	0.02	-3.06	< .001 ***
Morally acceptable cycling behavior	-0.28	0.03	-8.26	< .001***
Traffic education at school	0.006	0.002	2.25	.02 *
Traffic education at home	-0.006	0.003	-2.75	.001 **
Bike use	0.05	0.01	4.02	.002 **

*** indicates $p < .001$, ** indicates $p < 0.01$, * indicates $p < .05$

5. Discussion

With this thesis, we aimed to provide insights into children aged 11 to 13 in the Netherlands and their use of bikes, their involvement in collisions, and the demonstration of each higher-order cycling skill: decision-making at intersections (DMI), hazard perception (HP), gap acceptance (GA), and morally acceptable cycling behavior (MACB). We also analyzed the impact of traffic education at home and at school on each HOCS, and lastly, we investigated the effects of traffic education on higher-order skills performance and involvement in collisions.

5.1. Bicycle use and involvement in collisions

The way children aged 12 to 13 used their bikes in the Netherlands varied significantly across years and provinces, which suggests inconsistency in the results. In addition, the year 2022 (compared to 2020) was associated with a significantly higher probability of cyclists being involved in collisions from occurring. Nevertheless, it suggests other variables play an important role both bike use and collision involvement.

For example, the inconsistency in bike use and collision involvement could be partly due to the increased popularity of electric bikes in the Netherlands. E-bikes have accounted for the majority of bike sales since 2020, comprising 52% of the market in 2021 and increasing to 57% in both 2022 and 2023 (Statista, April 1, 2024). Other differences could be due to provincial variations explained by differences in infrastructure or the population density of provinces in the Netherlands.

5.2. Demonstration of higher-order cycling skills

In terms of higher-order cycling skills, alarmingly, out of every 10 children, around 6 did not reach the standard for both decision-making at intersections and hazard perception. For morally acceptable cycling behavior, half of the children did not meet the standard, and for gap acceptance, while slightly better than the other high-order cycling skills, 4 out of 10 children still did not achieve an acceptable score. This clearly demonstrates that young cyclists in the Netherlands have underdeveloped complex cycling skills, the same skills that have been identified as essential for safe cycling (Hukker & Vissers, 2023).

In addition, we also found that HP had significantly lower scores over time and that provincial differences for HP, GA, and MACB emerged. More specifically, while participants in Zeeland scored the lowest for HP, participants scored the highest for MACB, and highest for GA (more risk). Participants in South Holland, on the other hand, scored the highest for HP but the lowest for MACB. Participants in the province of Drenthe scored the least for GA. There were inconsistent scores for DMI across years and provinces. Future research could investigate potential reasons contributing to these differences to better understand potential factors contributing to these differences.

5.3. Traffic education as a predictor of higher-order cycling skills

5.3.1. Traffic education

Traffic education at school appeared to be reportedly more intensive than traffic education at home. Furthermore, for traffic education at school, there is a general increase in intensity over time while for traffic education at home, there is a decrease over the years. In addition, North Holland was the province's lowest average for traffic education at school, while Zeeland was the highest. For traffic education at home, Drenthe had the lowest average while Groningen had the highest mean.

5.3.2. Impact of traffic education on higher-order cycling skills

In relation to the higher-order cycling skills, traffic education, both school and home, showed varied effects on the demonstration of the HOCS. For morally acceptable cycling behavior, we found that formal traffic education decreased the scores, thereby representing children exhibiting increased unacceptable behavior while cycling and less safe crossing margins.

These finding is alarming. As traffic education increases, it seems to impact negatively two of the higher-order cycling skills and no significant impact on the other three higher-order cycling skills. This creates the need for reflection and raises important questions about the role, consistency, and effectiveness of traffic education curricula in schools in the Netherlands, given the differences observed across provinces and years. As each province is responsible for developing its own traffic education curriculum, it makes it difficult to analyze each traffic education program and understand how it impacts skill development. Hence, further research is needed to analyze traffic education curricula, examining how content varies between provinces, and how traffic education is taught, to better understand the reasons why traffic education at school negatively impacts the development of two higher-order cycling skills.

In addition, we found that informal traffic education decreased decision-making at intersections scores, suggesting that children with more informal traffic education leads to increased skills of decisions-making at intersections. It also increased morally acceptable cycling behavior scores. One explanation for this is model learning, where children observe their caretakers' cycling behavior and mirror it (Bianchi & Summala, 2004). This could be particularly relevant for DMI and MACB, as children learn cycling behaviors and actions to take while cycling, such as navigating intersections, through observing their parents (Bianchi & Summala, 2004). This therefore aligns with Bandura's Social Learning Theory, which emphasizes observational learning in child development (Bandura, 1969).

5.3.3. Impact of student characteristics on higher-order cycling skills

In terms of student characteristics, gender influenced the demonstration of morally acceptable cycling behavior, with females showing higher morally acceptable cycling behavior than males. This aligns with past research which also found that boys engaged in riskier behaviors and were more likely to take risks than girls while cycling (Useche et al., 2018; Wang et al., 2020).

In addition, increased bike use was associated with reduced MACB scores. In other words, as cyclists increase their cycling frequency, their cycling behavior appears to worsen and become less morally acceptable. One potential explanation for this is that as cyclists spend more time on the road, it correlates to increased rates of risky behaviors, maneuvers, and cycling errors (Adam et al., 2023; Useche et al., 2019). In addition, increased time on the road has also been associated with higher levels of cycling anger (Møller & Haustein, 2017; Stephens et al., 2019). One possible explanation for these findings is that higher exposure to traffic increases the frequency of interactions with other road users such as motor vehicles, which have been found to evoke negative emotions in cyclists (Huemer et al., 2018; O'Hern et al., 2019; Useche et al., 2019). Hence, increased bike use could trigger both increased negative emotions, and more opportunities for risky behavior and navigational errors, which could thus exacerbate morally unacceptable cycling behaviors (Adam et al., 2023).

Another reason bike use might negatively impact MACB could be the increased confidence gained through familiarity with the environment (Twisk et al., 2018). In the Netherlands, where children frequently cycle to school, repeated exposure allows them to gain familiarity with their environment, cycling skills, and traffic rules. However, this increased confidence may sometimes result in overconfidence, which can lead to risky behavior (Twisk et al., 2018).

Lastly, academic advice was associated with higher performance in the subtests of decision-making at intersections and morally acceptable cycling behavior. It is important to note that academic advice is an under-researched topic because of its specificity to the education system in the Netherlands. Moreover, academic advice is itself a prediction rather than being based on the actual education followed. Nevertheless, there could be an explanation for increased levels of this factor on DMI and MACB scores.

Academic advice, which is based on intelligence and social-emotional skills, could play a role in the development of these skills. First, in a previous study, it was found that children tend to prioritize motor over cognitive functions when a task involves both (Schaefer et al., 2008). Determining who has right-of-way or perceiving hazards in traffic situations, requires higher cognitive functioning. Furthermore, hazard perception requires attention to salient elements in the environment. A student with a higher academic advice may be able to handle higher loads of cognitive information and thus contribute to higher scores of hazard perceptions. Furthermore, morally acceptable cycling behavior is closely linked to social-emotional skills. Since academic advice reflects both cognitive and social-emotional development, students with higher secondary education advice are likely to possess more advanced competencies in these areas, which may explain their higher scores on MACB (Dijks et al., 2020).

5.4. Relation between traffic education, higher-order cycling skills, and cycling safety outcomes

5.4.1. Impact of traffic education on cycling safety outcomes

Traffic education at school has been found to increase the odds of collisions. As previously mentioned, analyses on each traffic education curriculum: the content taught, the learning objectives used, etc., is either limited or non-existent. While the overarching aim of traffic education is to improve cycling safety outcomes for children, the curriculum is not standardized, as each province develops its own traffic education program.

One study evaluated the traffic education curriculum in the province of Limburg (Feenstra et al., 2014). It argued that the program lacked systematic development and was not grounded in theoretical principles but was rather used to confront students with the reality of accidents and victims of collisions through graphic videos (Feenstra et al., 2014). Such an approach may not be the most effective method for teaching traffic education to students.

Traffic education at home was found to decrease the odds of collisions. This could be explained that as parents accompany and familiarize their children with traffic situations, they also play an exemplary role. Through model learning and observations of the parent (Bandura, 1969; Bianchi & Summala, 2004;), children inadvertently learn how to be safer cyclists on the road. Furthermore, parents may share knowledge about traffic situations and show skills that better equip children for safe traffic participation (Hoekstra & Twisk, 2010). Hence, parents play an important and positive role in the safety outcomes of their children.

5.4.2. Impact of higher-order cycling skills on cycling safety outcomes

Decision-making at intersections was associated with decreasing the odds of collisions, which is aligned with previous research (Hukker & Vissers, 2023; Liikenneturva, 2023; Schaefer et al., 2008). As intersections are points in traffic where multiple traffic flows meet, it often leads to abrupt changes, and a higher probability of conflicts (Uijtdewilligen et al., 2024). Hence, as children develop their DMI skills by improving their ability to make decisions and carry out cycling tasks at intersections using traffic rules, they are more likely to navigate these traffic situations in a safer way, contributing to a lower risk of collisions.

Additionally, we found that cyclists who demonstrated more morally acceptable cycling behavior were less likely to be involved in collisions. This finding is consistent with previous research showing that lower MACB scores are linked to a higher risk of accidents (Kummeneje & Rundmo, 2020; Twisk et al., 2015; Useche et al., 2021). Since MACB encompasses attitudes toward traffic rules, lower scores may reflect greater dissatisfaction and more negative attitudes toward traffic rules, which tends to increase the likelihood of collisions.

Another reason for MACB increasing the likelihood of collision involvement could be due to related to performing secondary tasks, such as using phones, earbuds, or conversing while cyclists, which are common distractions among cyclists (Ethan et al., 2016; Lambrecht & Sommer, 2021; Wolfe et al., 2016). These secondary tasks, especially involving technology (Terzano, 2013), have been shown to lead to riskier behaviors, creating unsafe traffic situations and increasing the odds of being involved in collisions and other general dangers (Goldenbeld et al., 2012).

Furthermore, the interactions between cyclists and how cyclists bike together, which is also a part of MACB, could be another reason for this HCOS's role in reduced safety outcomes. Duo cyclists, defined as two cyclists riding next to each other or cycling two abreast, are 1.5 to 15 times more likely to be involved in dangerous traffic situations and conflicts compared to solo cyclists (Odijk, 2023). It is common to see traditional cyclists holding onto electric bike riders, thereby riding side-by-side to reduce their own pedaling efforts. However, while this behavior occurs informally, it is not widely documented. Future research should investigate the behavior between e-bikes and traditional bikes and its potential relationship to collision involvement.

5.4.3. Impact of student characteristics on cycling safety outcomes

Bike use was associated with an increased risk of collisions. One explanation could be that as cyclists are exposed to and involved in traffic situations for longer periods of time, it contributes to a higher likelihood of accidents (Twisk & Vlakveld, 2019). Another explanation could be that as adolescents commute to school, they are biking during peak hours when cycling lanes are the most congested (De Lange et al., 2017). Involvement in collisions during peak hours is higher than at any other time during the day (Uijtdewilligen et al., 2024). Hence, both increased exposure to traffic and the high congestion of cycling lanes during peak hours when children are going to and from school could contribute to the increased likelihood of collisions.

6. Conclusion

This study explored higher-order cycling skills (HOCS) in children aged 11 to 13 through the WEVER project, assessing cycling skills to evaluate traffic education effectiveness in the Netherlands, with the aim of enhancing children's safety while cycling.

Despite the nationwide implementation of mandatory traffic education throughout primary school in the Netherlands, results from the WEVER test revealed that the demonstration of HOCS in children remains a serious concern. Approximately half of the children failed to meet the standard in three of the four HOCS: decision-making at intersections (DMI), hazard perception (HP), and morally acceptable cycling behavior (MACB). Gap acceptance (GA) was the only exception that performed above the threshold, though only marginally. Furthermore, nearly 2 in 5 children reported having been involved in a collision with either objects or other road users in both 2020 and 2022.

Disturbingly, formal traffic education at school was negatively associated with the performance of morally acceptable cycling behaviors, while not having any effect on the other three higher-order cycling skills and increasing the likelihood of being involved in collisions.

While these results are concerning, they do not imply that traffic education at school should be discontinued. The WEVER project is the first to evaluate the Dutch traffic education according to content of the curriculum. Hence, provinces should use these insights as encouragement to find ways to redesign traffic education curricula more effectively, inform content development, and integrate pedagogical approaches that better support the development of higher-order cycling skills.

In addition, future research could investigate in more depth the reasons behind collisions to gain a better understanding of these incidents. This includes finding out why and how these events happened. With these insights, further adjustments to the traffic education curricula could be made to ensure the traffic education program remain relevant for school children.

Traffic education at home on the other hand, negatively impacted DMI, but positively affected MACB. Informal traffic education was also found to reduce the risks of collisions, highlighting the importance of parents' role in their child's safety and skill development. This is in line with Bandura's social learning theory: learning through observation and by example, the context here being safe cycling behavior modeled by parents. Future research could investigate potential parental initiatives to support and help them gain awareness of the role they play in developing higher-order cycling skills and their children's traffic safety outcomes

Decision-making at intersections and morally acceptable cycling behavior were associated with improving safety outcomes. This is notable, as this suggests that behaving morally well in traffic situations and knowing rights-of-way enhances safety more than accepting too-short gaps or being able to perceive hazards. Curriculum development could therefore further develop these two skills, and seeing that morally acceptable cycling behavior is enhanced by traffic education at home, future initiatives could involve caretakers to potentially further the impact of traffic education at home.

Increased bike use was associated with a higher likelihood of collision involvement, possibly due to the increased exposure to dangers on the road or cycling during peak hours when bike lanes are more congested. As newly transitioned middle schoolers from elementary school often ride longer distances to their new school, it is essential they have well-developed cycling skills to navigate complex traffic and mitigate unsafe situations while cycling. Furthermore, bike use was negatively associated with MACB, which could be explained by increased exposure to traffic situations, increased emotional responses to traffic situations, or overconfidence due to environmental familiarity. Seeing the impact of MACB on cycling safety outcomes, this further provides reason to develop this higher-order cycling skill in traffic education curricula.

Although academic advice is poorly researched due to its specificity to the Dutch education system, higher academic advice was associated with scores in decision-making at intersections, hazard perception, and morally acceptable cycling behavior. Perhaps targeted traffic education at school could ensure all children, regardless of their academic advice have additional time to develop these crucial cycling skills which have been identified to play a role in cycling safety outcomes.

All in all, this thesis has contributed to research on cycling safety among children examining the role of traffic education at school and at home, on the development of higher-order cycling skills, and the role of traffic education and the HOCS on safety outcomes of children in the Netherlands. These insights are crucial for revising and improving traffic education curricula, as well as potentially developing new initiatives, such as parental support programs to help parents increase skill development in their children and improve their cycling safety outcomes.

7. Limitations

This study has several limitations that should be considered when interpreting the findings. First, the WEVER test uses a scenario-based questionnaire which could involve a certain source of bias in the way participants respond to items, based on the situations. Although the WEVER test has been validated and analysis showed reliable and accurate items for each test suite, it cannot fully capture children's real-life behaviors, such as the risks they take, their decision-making at intersections, or their hazard perception in actual traffic conditions. Nevertheless, conducting the test in real traffic was not possible due to the ethical concerns associated with exposing children to dangerous situations and conditions, and recording their behavior, reactions, or actions.

Furthermore, as the WEVER test is based on self-assessment, it partly relies on self-reported data regarding morally acceptable cycling behavior and collision involvement. For this reason, there are certain limitations. Specifically, it is difficult to assess whether participants can accurately respond to the test items due to the potential overestimation of their own abilities and the influence of social desirability, both of which could introduce biases. For example, children may contribute to more violations and errors while cycling than they mention (Twisk et al., 2018). As a result, this could lead to inflated self-reports.

Similarly, collision involvement is based on self-reports. The data gathered may not provide the full picture of these events from occurring. Research by Chapman and Underwood (2000) found that the self-report of collisions and near collisions is poor and prone to being forgotten. More specifically, they found that up to 80% of near-miss events were forgotten after a two-week delay. However, collisions, while also forgotten, were less likely to be forgotten, especially if the test-taker was at fault themselves (Chapman & Underwood, 2000).

In terms of school sampling, schools in each province were contacted by the provincially appointed IPO representative, and their participation was voluntary. It is unclear whether these representatives prioritized schools with safety labels, which could result in a participant sample that is not fully representative. Furthermore, there was no deliberate sampling frame used to ensure equal representation of school and student characteristics. The lack of a sampling frame, and thereby the absence of strata, could have impacted the extent to which the schools were representative of schools within provinces and, in general, of the Netherlands.

In addition, a few factors led to sparse data. First, in the administration of the WEVER test suite, there were some technical failures, which resulted in responses not being saved. Secondly, small sample sizes for certain provinces led to unequal sample sizes across all years (2017, 2019, 2020 and 2022). These technical failures and varying sample sizes led to the decision to only use the data from 2020 and 2022, allowing for more complete datasets and more robust analysis.

Lastly, the standards set by the WEVER project for each HOCS require further analysis with a critical eye. The current standards were set based on predictions of the scores. As a result, they could reflect misaligned expectations, either as unrealistic benchmarks that set the bar too high or as insufficiently challenging criteria that set the bar too low. While the latter may be less probable, it would not be wise to exclude this possibility. Nevertheless, the standards currently used by the WEVER project offer applicability and highlight the potential for identifying the performance levels of the HOCS, which could subsequently be used in the development of traffic education curricula in the Netherlands.

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