HAPTIC FEEDBACK FOR IMPROVED SAFETY OF ELDERLY E-BIKE USERS IN V2X URBAN ENVIRONMENTS: DEVELOPMENT AND EVALUATION OF VIBRATING HELMET AND VIBRATING HANDLEBARS

Master graduation thesis

Written by Luc Joël Jansen

MSc Integrated Product Design

Faculty of Industrial Design Engineering

Delft University of Technology

TU Delft

MODYN

MASTER
GRADUATION THESIS

Haptic feedback for improved safety of elderly e-bike users in V2X urban environments:
Development and evaluation of vibrating helmet and vibrating handlebar

Written by Luc Joël Jansen (student no. 4824490)

Msc Integrated Product Design

Faculty of Industrial Design Engineering

Delft University of Technology

Supervisory team TU Delft:

Ir. J.R. Alferink (Mentor)

S.M. Persaud Msc (Chair)

MODYN

Industrieweg 8, 4191 NV, Geldermalsen

Supervisor MODYN:

MA Gert-Jan van Breugel (Managing Director)

April 15th, 2026

THESIS
PREFACE

With the completion of this thesis, I am submitting my final piece of work for my Master's in Integrated Product Design and, with that, I am bringing my time at TU Delft to a close after seven eventful years. Although my Master's project was, in principle, an individual project, I was fortunate enough to receive a great deal of help and guidance, for which I am incredibly grateful.

First, I would like to thank my supervisors Joost Alferink and Stefan Persaud immensely for their support and positive feedback throughout the entire project. They recognised where I was struggling, gave clear feedback on my progress and gave me a great deal of confidence and guidance, particularly at times when the project was becoming a bit too much for me, with potential future applications that simply proved unfeasible within a timeframe of approximately twenty weeks. I would like to thank Joost for his enthusiasm when I contacted him to mentor me, the trust he placed in me and for putting me in touch with MODYN; a great organisation with extensive expertise in the field of mobility, which enabled me to develop my vision in the way it needed to be.

Second, I would like to thank MODYN, in particularly Gert-Jan van Breugel, who gave me the opportunity to develop my vision within a professional environment. I got all the support I needed and from day one I was introduced to various renowned stakeholders. Special thanks also to Dennis, who helped me with engineering and 3D-printing challenges.
In addition, I would like to thank Maarten Pelgrim from Gazelle in particular, for providing me with an e-bike, components, for the exchange of information and unpublished documentation & research and for facilitating the user testing within Gazelle.

I would also like to thank the people who participated in the user testing who enabled me to evaluate the design and the staff at the Experience Centre in Dieren for recruiting them.

Finally, I am grateful to my family and friends who supported me and stood by me at times when I needed it. I'd like to thank my parents for all their love, understanding and support. Thank you for always make a car available for me for driving to Geldermalsen, for letting me join you for dinner every evening, for letting me turn a bedroom into a work and craft room – with all the mess that entails – and for putting up with the noise of the 3D-printer at night.

REPORT **SUMMARY**

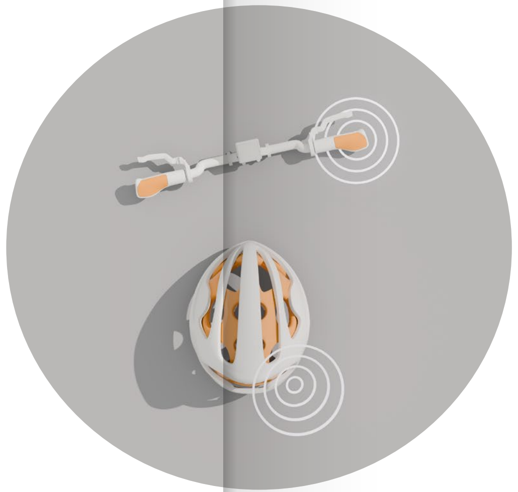
This graduation project explored how haptic feedback could be adapted to communicate navigation and safety cues with minimal distraction, enhancing the road user's perception and response in mixed urban traffic scenarios. A key area of investigation of the project was to improve the ease of use, intuitiveness and (perceived) safety for the elderly (e-)bike users. The challenge lied in understanding how such feedback could be integrated effectively into the cycling experience and in defining what makes cues clear, distinguishable, and context appropriate. The project is designed towards the future vision, on an urban scenario, in which low-traffic policies and active mobility have been further developed and in which digital infrastructure is broader integrated into the transport systems, which means that vehicles, infrastructure and users have increasingly become part of an interconnected ecosystem.

The design resulted in a **directional haptic interface** with two contact points: the helmet and the handles. The helmet is used for spatial feedback around the head, and the handles for local directional cues in the hands. Together, they form one connected warning system. The system is translated into a prototype, that includes a haptic helmet, head tracking, vibrating handles, a link between bicycle and helmet, a simulated digital test environment, a web-based interface and a fixed-base simulator for controlled user testing.

This project was carried out using the **Double Diamond model**, comprising the phases of Discovery, Definition, Development and Delivery, and was concluded with a design evaluation. The process began with a context analysis, followed by the formulation of the problem statement. The vision was then defined based on design principles, success criteria, scope and conceptual direction. In the final phase, the design was worked out in detail. A helmet module and a handlebar module were built, including microcontrollers, vibration motors, haptic drivers, IMUs, batteries, and wireless communication between bicycle and helmet. A handle prototype was developed through 3D scanning, digital modelling, 3D-printing, and material testing. Finally, a software architecture was developed to connect the simulator, server, gateway, handle node, and helmet node. This made it possible to play traffic scenarios, trigger warnings, and translate bicycle-based hazard data into rider-based haptic feedback.

User testing was conducted to evaluate whether directional haptic feedback via vibrating handles and a vibrating helmet would be experienced as an acceptable interaction modality in a desktop-based simulated cycling context, with specific attention to workload, usefulness, satisfaction, clarity/interpretability and perceived safety/irritation.

The user evaluation showed that directional haptic feedback has clear potential as an interaction modality for cycling-related hazard warnings. The prototype was generally experienced as useful, reasonably satisfying and not overly demanding. The helmet performed best in term of directional clarity and interpretability, while the handles offered more practical appeal but weaker interpretative performance. It shows that the central challenge is not only technical feasibility, but the translation of connected traffic information into a warning that is supportive, acceptable, and behaviourally appropriate.



REPORT **GLOSSARY**

B2X	Bike to Everything. More specifically Vehicle-to-Everything applied to bicycles.
HMI	Human-machine interaction
I2C	Inter-Integrated Circuit
IMU	Inertial Measurement Unit
NLOS	Non-Line-of-Sight
PoT	Proof of Technology
PoV	Proof of Value
TTC	Time-to-Collision
TPU	Thermoplastic Polyurethane
V2X	Vehicle-to-Everything. By digitally connecting vehicles, infrastructure and other road users, information about position, speed and direction of travel can be shared.
ViP approach	Vision in Product Design approach: the existing situation is first analysed and a future oriented interaction vision is then developed.

TABLE OF CONTENTS

REPORT **INTRODUCTION**

SITUATION

The safety of road users in urban areas is at risk. It appears that especially cyclists are vulnerable. Numbers indicate for example that in the Netherlands in 2021 there were 207 people who got involved in a traffic accident and who did not survive and that 75 people (36%) of all these fatalities concerned cyclists (SWOV, 2023). Within this group, the proportion of older people is high; almost three-quarters of fatal cycling casualties are aged 60 or over (Koninklijke Gazelle [Gazelle] & Pelgrim, 2025; SWOV, 2023). The safety of older cyclists therefore presents an urgent design challenge, particularly as e-bike use is increasing within this group (SWOV, 2022; SWOV, 2024). In addition, urban traffic situations are becoming more complex due to a greater diversity of vehicles and speeds on cycle paths (Al-Taie et al., 2024; SWOV, 2022).

PROBLEM STATEMENT

The development of Vehicle-to-Everything (V2X), more specific Bike-to-Everything (B2x) really offers opportunities to improve road safety. By using technology to digitally connect vehicles on the road, infrastructure and other road users, it is possible to share important information. This information includes things like speed and the direction of travel. This form of digital visibility can be especially helpful in situations with limited sightlines. Being able to see what is going on around you, this form of digital visibility can be crucial in preventing road accidents (Bosch Accident Research, 2025). However, the technical availability of this data does not in itself guarantee safe interaction. Current warning systems often rely on visual or auditory feedback, yet it is precisely these channels that are already heavily taxed during road use and can be particularly problematic for older cyclists (Gong, 2024; Nukarinen et al., 2015; SWOV, 2023, 2024). Although B2X systems can detect hazards outside the direct line of sight, there is still no low-load interface that translates this information to the cyclist in a timely and directional manner.

DESIGN CHALLENGE

The core of this project is the mismatch between the availability of digital traffic information and the way in which this information is presented. It led to the central design challenge of this project:

How can B2X safety information in NLOS situations be translated into a directional haptic interface that alerts elderly cyclists with enough time to spare, without causing additional visual strain or prompting unsafe evasive actions?

VISION

Based on this observation, this project focuses on vibrotactile feedback as an alternative communication channel for early B2X warnings on e-bikes. The central premise is that hazard information does not need to be read or listened to but can be made spatially perceptible through the body (Jansen et al., 2018). The contribution of this project lies in the development of a research platform in which future B2X scenarios are translated into a testable prototype for the over-60s demographic. The aim is not only to investigate technical feasibility, but also to explore how a haptic interface can contribute to safer interaction between older cyclists and a future connected traffic environment.

PROJECT APPROACH

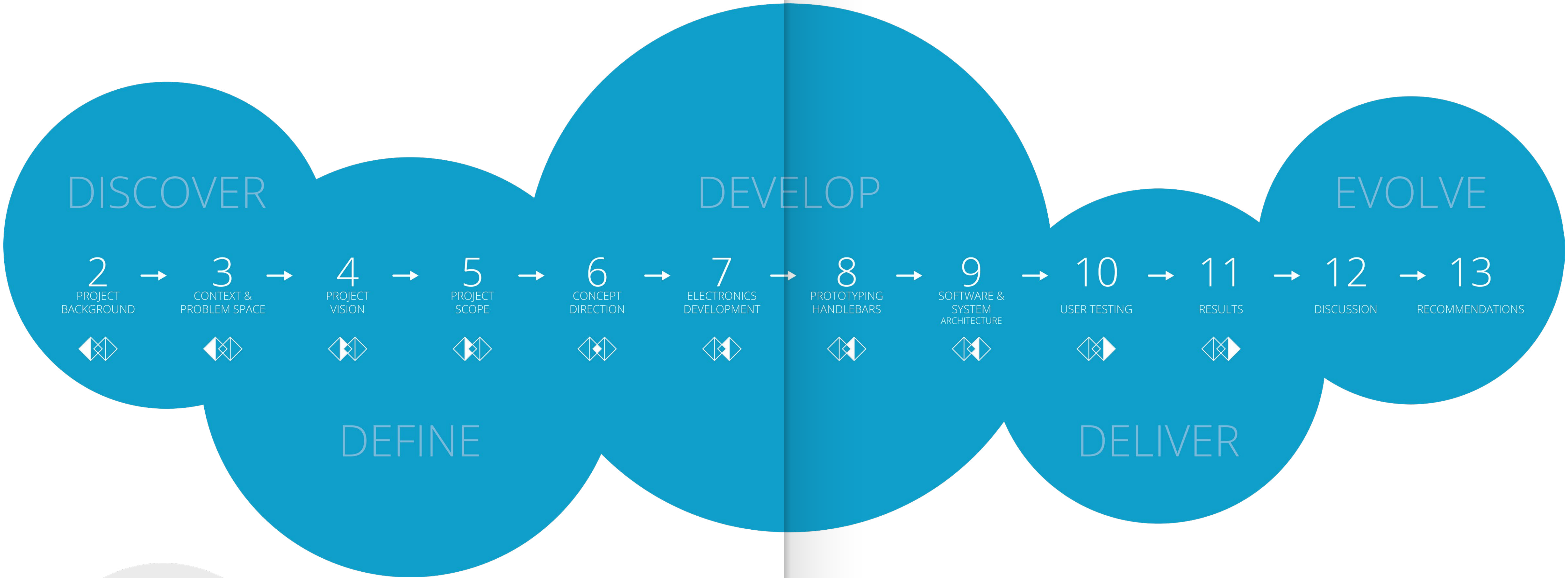
The project was approached by an iterative, hands-on methodology, working in short Agile sprints with weekly targets and stakeholder evaluations. It was carried out using the Double Diamond model, comprising the phases of Discovery, Definition, Development and Delivery, and was concluded with a design evaluation. The process began with a context analysis, followed by the formulation of the problem statement. The vision was then defined based on design principles, success criteria, scope and conceptual direction. In the final phase, the design was worked out in detail. Lastly the design was evaluated by user testing.

MODYN

This graduation project was primarily conceived and carried out autonomously. However, given that the complexity of the design required the necessary expertise and supervision, a company was sought within which the project could be carried out. The MODYN organisation came into the picture. It is a renowned design agency that perfectly aligns with my vision ("Dedicated to designing new futures, pushing the boundaries and creating products people love") and has extensive expertise and connections in the field of mobility (Modyn, 2026). This project was carried out at MODYN and partly from home. The user testing were largely conducted at the company Gazelle.

OUTLINE

This report provides a detailed explanation of the project in various sections in line with the project approach. The sections covered are, first, the Project background & evolution of the design brief (Chapter 2), followed by the Context & problem space (Chapter 3) and the Project vision (Chapter 4). It then covers the Project scope (Chapter 5), the Concept direction (Chapter 6), the Electronics prototype development (Chapter 7), the Prototyping of the handlebar (Chapter 8), the Software and system architecture (Chapter 9) and the User testing (Chapter 10). Finally, the report concludes with the Results (Chapter 11), the Discussion (Chapter 12) and the Recommendations (Chapter 13).


DISCOVER
DEVELOP
EVOLVE
2 PROJECT BACKGROUND
3 CONTEXT & PROBLEM SPACE
4 PROJECT VISION
5 PROJECT SCOPE
6 CONCEPT DIRECTION
7 ELECTRONICS DEVELOPMENT
8 PROTOTYPING HANDLEBARS
9 SOFTWARE & SYSTEM ARCHITECTURE
10 USER TESTING
11 RESULTS
12 DISCUSSION
13 RECOMMENDATIONS
DEFINE
DELIVER

DUBBLE DIAMOND
DISCOVER
DEFINE
DIRECTION
DEVELOP
DELIVER

PROJECT BACKGROUND
EVOLUTION OF THE DESIGN BRIEF

HOW THE PROJECT EVOLVED FROM EXPLORATION TO USER VALUE

Exploration →
- Smart e-bike as future product
- Supportive functions for cycling
- Ease of use, trust and safety

Transition →
- Focus shift towards safety
- Digital visibility became relevant
- Multimodal feedback gained importance

Interaction →
- From information to experience
- Low-load feedback during cycling
- Towards a "Sixth Sense"

Value
- More data is not always better
- Interaction quality became central
- Meaningful support for the user

This chapter covers the evolution towards targeted design of directional haptic warnings. It explains how the project evolved from a broad exploration of the smart e-bike and V2X technology into focused research on presenting digital traffic information in a way that supports elderly cyclists through intuitive, non-intrusive haptic alerts. It describes the two ViP phases and the step to Proof of Value.

This graduation project originated from a broad interest in the smart e-bike as a future product. In the initial phase, the focus was not immediately on B2X or haptic feedback, but on the question of how the e-bike could evolve from a mechanical mode of transport into a smarter, supportive system. In this context, the idea of smart assistance functions similar to those in the automotive sector played an important role: functions that not only add technology but actively contribute to convenience, safety and confidence whilst cycling (Ryu et al., 2024).

Based on this broad exploration, this project examined the role of smart functions on and around the bicycle. Initially, this focused on the general question of which forms of support could be relevant and meaningful for e-bike users. Gradually, the focus shifted increasingly towards safety and intuitive interaction, as it was precisely in these areas that the social relevance and design urgency proved to be greatest (Silla et al., 2016). Shortly afterwards, the question of multimodal feedback for smart e-bike users also came more prominently into focus within the project context.

A key turning point in this development was subsequently a discussion with Maarten Pelgrim, Innovation Manager at Gazelle, during which the potential of V2X technology for the cycling context was explicitly highlighted. That conversation brought about a clear acceleration in the project's importance, as it shifted the focus from general smart e-bike functions to connected safety and digital visibility in traffic situations where natural perception falls short (Koninklijke Gazelle [Gazelle] & Pelgrim, 2025). Within MODYN, too, V2X was already a familiar and relevant direction, meaning that this focus was not only suggested externally but also confirmed from within the project environment.

As the project progressed, it became clear that the technical availability of connected data is only one part of the challenge (Raddaoui, 2023). The real design challenge lies not only in being able to detect or share traffic information, but above all in the question of how this information can be presented in a way that is usable, understandable and non-disruptive

whilst cycling (Huang, 2020; Raddaoui, 2023). This shift took on added significance due to the decision to focus the project on elderly cyclists as a specific target group. Consequently, the project evolved from a broad exploration of smart e-bike functions into a targeted, human-centred safety question: how can digital traffic information be designed in such a way that it supports elderly cyclists rather than placing a burden on them?

Within this process, work was carried out in accordance with the Vision in Product Design (ViP) approach, in which the existing situation is first analysed and a future-oriented interaction vision is then developed (Hekkert & Van, n.d.). The evolution of the design brief illustrates how an initially broad exploration of smart e-bikes has gradually converged into a specific design question concerning directional haptic alerts for elderly cyclists.

2.1 VIP PHASE 1: DECONSTRUCTION OF THE STATUS QUO

In the first ViP phase, the existing situation was analysed. In doing so, the e-bike was approached as a product situated between a traditional bicycle and a smart, connected vehicle. Electric assistance has not only made the bicycle more accessible, but has also transformed it into a means of transport capable of covering greater distances and reaching higher speeds (SWOV – Instituut voor Wetenschappelijk Onderzoek Verkeersveiligheid, 2022). For elderly users in particular, this leads to greater exposure to traffic situations requiring rapid perception, interpretation and action (SWOV – Instituut voor Wetenschappelijk Onderzoek Verkeersveiligheid, 2022, 2024).

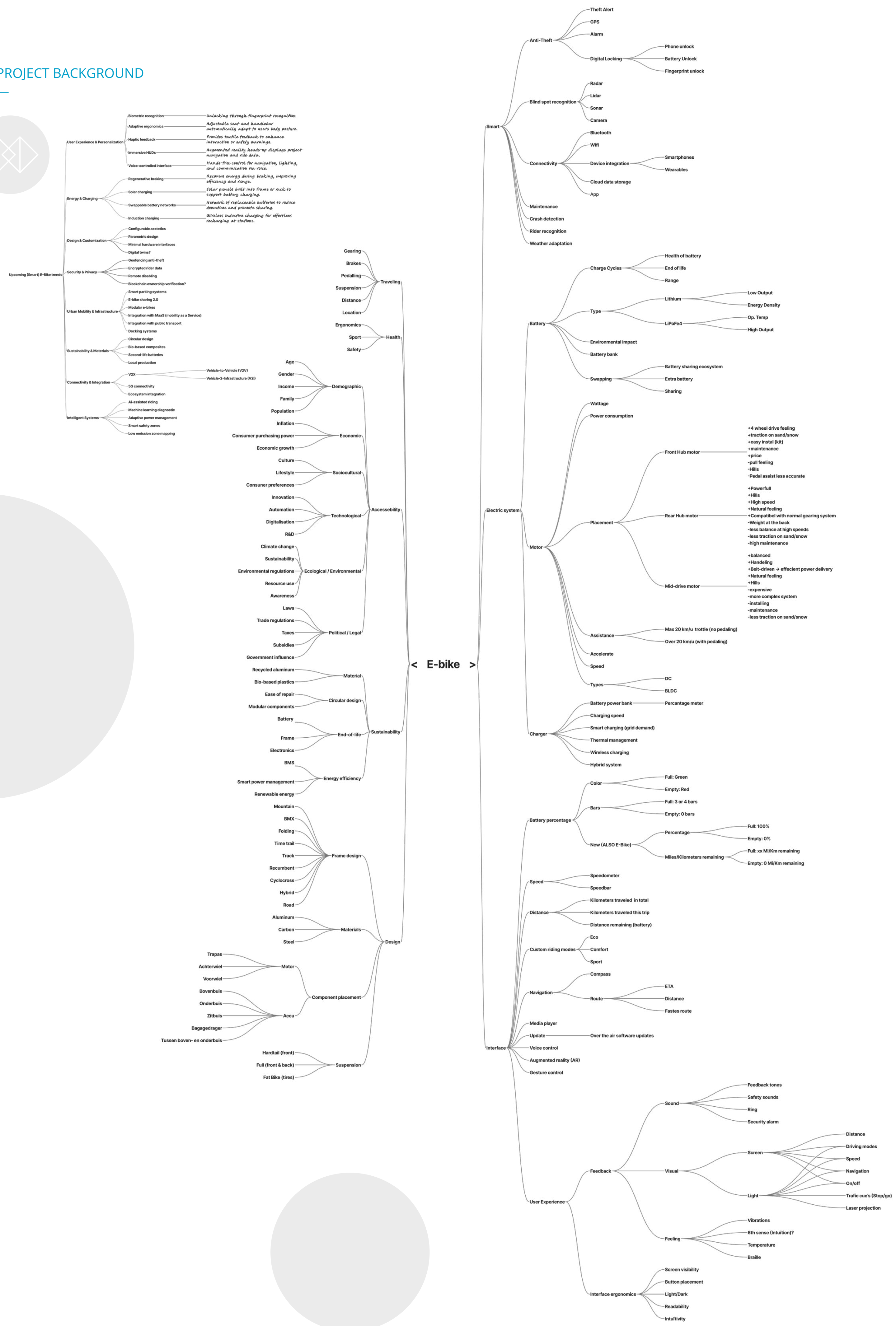
In this early phase, the project's scope was deliberately broad. The starting point was the question of what a smart e-bike might look like when intelligent, supportive functions become a logical part of the riding experience.

Because the focus was not only on safety, but also on ease of use, intuition and confidence, the project started not as a direct study of connected safety, but as a broader exploration of how technology can meaningfully improve the cycling experience.

It gradually became clear that the safety aspect, in particular, required further exploration. This was based, on the one hand, on a review of the literature and, on the other, on discussions with MODYN and Gazelle. During this phase, the question of multimodal feedback also arose: if a smart e-bike is to provide information, through which channel will this happen, and what does that mean for the user whilst cycling?. This question formed an important intermediate step between the original smart e-bike concept and the subsequent focus on haptic interaction.

In parallel with this exploration, the current design of smart bicycle systems was examined. Many existing solutions make use of displays, smartphone connections or auditory signals (Appendix C). This observation led to the insight that it is not only the content of traffic information that matters, but above all the way in which it is presented whilst cycling (Nukarinen et al., 2015; Weinschenk et al., 2011).

A key outcome of this phase was therefore the abandonment of the assumption that more information automatically leads to greater safety. The analysis of the current situation made it clear that an interface only becomes valuable when it aligns with the user's limitations, expectations and possibility for actions whilst driving (Gong, 2025; Raddaoui, 2023).



2.2 VIP PHASE 2: CONSTRUCTING THE “SIXTH SENSE”

Following the deconstruction phase in the ViP process, the second ViP phase involved developing a vision of the future in which the interaction between cyclists and the system is fundamentally different (Hekkert & Van, n.d.). Instead of an interface that constantly demands attention, the aim was to find an interface that remains in the background as much as possible and only intervenes when necessary (Raddaoui, 2023). This design guideline led to the concept of a ‘digital feeler’ or ‘Sixth Sense’: an additional sensory layer that alerts the cyclist to relevant threats at an early stage, without the need for screen interaction or continuous audible signals (Raddaoui, 2023).

This step can be understood as a further narrowing of the earlier questions regarding smart functions and multimodal feedback. Whilst the project began with the smart e-bike as a broad vision of the future, the focus shifted increasingly towards the question of which channel is truly suitable for safety-critical information in the cycling context. From this exploration, haptics emerged as a promising channel for early and spatial alerts, as it can convey this information through the body without placing additional demands on visual or auditory attention (Jansen et al., 2018; Nukarinen et al., 2015; Olaverri-Monreal & Jizba, 2016).

Within the project, this concept was translated into an interaction that is supportive and vigilant: present when needed, but otherwise as unobtrusive as possible in use (Raddaoui, 2023). This shifted the design question from “how can we provide smart or connected data on the bicycle?” to “how can we make hazard information perceptible in a way that is intuitive, early-warning and non-intrusive?” (Huang, 2020; Raddaoui, 2023). The choice of spatial haptics as the primary information carrier was therefore not a predetermined starting point, but the result of a design exploration in which the focus was gradually refined.

2.3 FROM PROOF OF TECHNOLOGY TO PROOF OF VALUE

Technical maturity does not automatically lead to user value (Raddaoui, 2023). The development of V2X systems demonstrates that a great deal of knowledge and infrastructure is available for collecting and sharing traffic data, but that the translation into meaningful user interaction often lags behind (Raddaoui, 2023). In the literature on innovation and mobility, this distinction is referred to as the step from Proof of Technology (PoT) to Proof of Value (PoV) (Raddaoui, 2023). Whereas PoT focuses on whether a technology functions technically, PoV asks whether the solution actually eliminates the user’s daily ‘pain points’ (Raddaoui, 2023).

Rather than emphasising the existence of a technically functioning connected system, the research focuses on whether such technology can actually provide meaningful support in practice.

This means that the focus is not on the development of B2X communication, but on the quality of the interaction: does the system help the user to act more calmly, alertly and safely? The goal is not to deliver a Minimum Viable Product (MVP), but a Minimum Lovable Product (MLP) that is useful, usable and appealing to the end-user (Raddaoui, 2023).

The prototype is therefore viewed not only as a technical object, but also as a research platform through which the practical value and acceptance of haptic B2X alerts can be investigated.

CONTEXT & **PROBLEM SPACE**

HOW THE CONTEXT AND PROBLEM SPACE DEFINE THE DESIGN CHALLENGE

Context	→	Visibility	→	Bottleneck	→	Design challenge
Urban traffic is becoming more complex		Hazards are not always directly visible		Information is not automatically usable		Haptics offers a low-load channel
Elderly cyclists face higher risks		NLOS situations reduce natural awareness		Visual and auditory cues demand attention		Early warnings support anticipation
Safety support becomes more relevant		B2X can create digital visibility		Interfaces can add mental strain		Directional feedback frames the problem statement

This chapter describes digital visibility in NLOS situations, HMI as a bottleneck, the haptic gap, the timing of warnings and finally the problem statement.

The urban mobility landscape is changing rapidly. It is getting busier on the cycle paths, the speed differences between road users are increasing and the distinction between conventional bicycles, e-bikes and other forms of mobility is becoming blurry (Al-Taie et al., 2024; SWOV, 2023). This development emphasizes the importance of interfaces that support safety without causing additional strain (Nukarinen et al., 2015; Olaverri-Monreal, 2016). This is especially important for elderly people, as they are more likely to get hurt. The chance of getting really injured or even killed is much higher for older cyclists than for younger road users (SWOV, 2023, 2024)

3.1 DIGITAL VISIBILITY IN NLOS SITUATIONS

A significant part of serious cycling accidents concern collisions with motorised traffic. About 70% of fatal cycling accidents in Europe result from a motorised vehicle collision (European Transport Safety Council [ETSC] et al., 2020; Pilgrim, 2025).

Dangerous conflicts arise particularly in situations where road users cannot see each other in time. Such situations are often described as Non-Line-of-Sight (NLOS): moments when objects are outside the direct line of sight due to buildings, parked vehicles or other obstacles (Tamir, 2025; Koninklijke Gazelle [Gazelle] & Pelgrim, 2025).

It is precisely in these situations that B2X can offer added value. By making road users digitally visible before they are physically visible, a new type of safety information is created that does not depend on direct observation (Tamir, 2025; Koninklijke Gazelle [Gazelle] & Pelgrim, 2025). Bosch Accident Research (2025) shows that visual obstruction is a relevant factor in car/cyclist conflicts and that B2X has particular potential in this area: visual obstruction is a factor in 24% of injury-causing conflicts, whilst the Field of Effect for B2X is estimated at approximately 29% of car/cyclist conflicts (Lich & Robert Bosch [Bosch], 2025; Koninklijke Gazelle [Gazelle] & Koninklijke Gazelle [Gazelle] & Pelgrim, 2025).

The core of the issue thus shifts from detection to communication: if the information is available, how should it be conveyed to the cyclist?

3.2 HMI AS A BOTTLENECK

The availability of digital traffic information does not automatically mean that it is usable. Human-machine interaction represents a significant bottleneck in this regard. Cycling is an activity that constantly requires a combination of balance, directional control and the ability to read the environment (SWOV – Instituut voor Wetenschappelijk Onderzoek Verkeersveiligheid, 2023, 2024). Additional information can be helpful, but only if it does not compete with the basic requirements of safe cycling (Nukarinen et al., 2015).

This is often the case with current systems. Visual interfaces require the cyclist to look away and make a conscious interpretation, whilst auditory signals are susceptible to masking by, for example, ambient noise (Nukarinen et al., 2015; Olaverri-Monreal & Jizba, 2016). Nukarinen et al. (2015) describe how visual and auditory instructions actually make use of resources that are essential for safe behaviour in traffic, and explicitly state that noisy environments can reduce the usability of auditory instructions. Although these resources can be informative, they all require explicit attention from the user. The literature shows that it is precisely this attention that is in short supply in traffic situations (Nukarinen et al., 2015). Visual and auditory instructions draw on sensory and cognitive resources that are already required for monitoring the driving environment (Nukarinen et al., 2015). This is underpinned by fundamental human factors: our short-term memory is limited, and processing new information requires considerable mental resources (Weinschenk et al., 2011). Furthermore, a focus on secondary information can lead to 'inattentional blindness', whereby critical changes in the environment go unnoticed (Weinschenk et al., 2011).

For elderly cyclists, this is even more problematic, as information processing can be slower and physical actions, such as looking behind, require greater effort (SWOV – Instituut voor Wetenschappelijk Onderzoek Verkeersveiligheid, 2024). In this context, SWOV-Ouderen in Het Verkeer (2024) cites, among other things, delayed information processing, balance problems and limitations in mobility and orientation as relevant factors for elderly road users.

This creates a paradox: a system designed to improve safety can actually lead to additional mental strain or unsafe actions if they are not properly tailored to the context of use (Gong, 2025; Raddaoui, 2023). This means that the interface is a not a mere detail, but a core component of road safety.

3.3 THE HAPTIC GAP

In contrast to the limitations of visual and auditory feedback, there is a relatively underutilised channel: haptics. Vibrotactile signals can convey information without screen interaction and without being dependent on sound conditions (Nukarinen et al., 2015). Research by Nukarinen et al. (2015) shows that directional haptic cues can be processed more quickly than visual text instructions and are also perceived as less frustrating; in their study, participants responded significantly faster to directional haptic cues than to visual text cues.

Despite this potential, haptics in cycling interfaces are often still limited to signals that may draw attention but provide little information about origin or urgency. This creates a haptic gap: whilst there is potential for tactile communication, there is still little validated interaction logic that translates hazard information in a spatial and intuitive manner to the cyclist's body.

This project addresses that gap. The central premise being that spatial haptics can function not only as a warning, but as a form of directional alerting that supports situational awareness without causing additional visual load.

This shifts the design question from how hazard information can be displayed to how hazard information can be experienced physically and intuitively.

3.4 TIMING OF WARNINGS: EARLY WARNING VERSUS LATE WARNING

It is not only the modality of a warning that determines its effectiveness, but also the timing of its delivery. Straughn et al. (2009) demonstrate in a simulator study of tactile and auditory collision warnings that the relationship between warning effectiveness and stimulus-response compatibility depends on the Time-to-Collision (TTC). In their study, warnings were presented at a TTC of 4.0 s (early warning) or 2.0 s (late warning) (Straughn et al., 2009).

The results show that early warnings function fundamentally differently from late warnings. With an early warning, the user still has time to assess the situation, locate the source of the danger and then choose an appropriate response. Straughn et al. (2009) therefore conclude that, with a longer TTC, a warning that communicates the location of the danger may be more effective than a warning that immediately prescribes the evasion direction. In their study, early hazard location warnings were the most effective: these led to a shorter reaction time and a greater clearance distance than early evasion direction warnings (Straughn et al., 2009).

The situation is different in the case of a late warning. When the TTC is very short, the user has barely any time to assess the situation, and the function of the warning shifts from alerting to direct behavioural guidance. In the study by Straughn et al. (2009), it was precisely the evasion direction warnings that were most effective in the late warning condition. The authors also note that, with a TTC of 2.0 s, the warning often functioned more as guidance support than as a genuine warning, because drivers had often already initiated their evasion manoeuvre before the signal was presented (Straughn et al., 2009).

Although this study was conducted in a driving simulator and not in a cycling context, it provides a relevant theoretical basis for this project. For a B2X system aimed at early warning in NLOS situations, an early warning around TTC ≈ 4 s is therefore appropriate as a design strategy. In such a situation, it is not necessary to immediately issue an evasion or steering instruction; it is, in fact, more valuable to alert the cyclist, with enough reaction time, to the location of the hazard, so that situational awareness can develop before an acute startle response is required.

3.5 PROBLEM STATEMENT

The core of this graduation project is the mismatch between the availability of digital traffic information and the way in which this information is presented to cyclists. Although B2X systems can detect hazards outside the direct line of sight, there is still no low-load interface that translates this information to the cyclist in a timely and directional manner.

The central design challenge is therefore as follows: how can B2X safety information in NLOS situations be translated into a directional haptic interface that alerts elderly cyclists with enough time to spare, without causing additional visual strain or prompting unsafe evasive actions?

PROJECT **VISION**

This chapter describes the future scenario towards which this project is designed, the desired user experience and the vision's design principles and success criteria. The vision is deliberately speculative: not to predict the future with precision, but to formulate a guiding framework within which design choices for B2X feedback become logical and verifiable.

4.1 FUTURE ASSUMPTIONS AND CONTEXT (2030–2035)

The vision is based on an urban scenario, in which low-traffic policies and active mobility have been further developed. E-bikes and other forms of micromobility play a central role in everyday travel in this future. At the same time, digital infrastructure is broader integrated into the transport systems, which means that vehicles, infrastructure and users are becoming part of an interconnected ecosystem more and more.

In this scenario, V2X is no longer a standalone innovation, but an everyday layer of information that makes relevant traffic data available before it becomes visible. For elderly cyclists, this marks a shift from reactive adaptation tot proactive support. The environment around them does not necessarily become simpler, but it does become more intelligent in the way it shares and presents information.

This vision of the future is consistent with current trends. The Coalition for Cyclist Safety explicitly positions V2X as a means to make cyclists "digitally visible" within a broader traffic system and emphasises that this is only possible through collaboration between multiple parties from the automotive, cycling, and technology sectors (Coalition for Cyclist Safety [C4CS], 2025). Parties like Bosch, CARIAD, and other coalition members also describe V2X as a route towards a broader ecosystem in which vehicles, bicycles, and infrastructure can mutually identify and alert one another (CARIAD Joins Coalition for Greater Road Safety Through V2X Technology, n.d.).

At the same time, this vision does not assume that greater connectivity automatically leads to better interaction. As more forms of mobility become part of the same network, there is also a risk that users will be exposed to an overload of information and notifications. The future value of B2X will therefore depend not only on the availability of data, but also on the quality of filtering and prioritisation.

4.2 DESIRED USER EXPERIENCE: THE “SIXTH SENSE”

Within this vision for the future, the desired experience is that of an additional sensory layer: a “Sixth Sense” that makes dangers perceptible at an early stage. The cyclist does not need to read danger information on a screen or interpret it from a sound, but experiences it directly as a spatial cue on the body. The interfaces thus stays in the background as much as possible while being instantly accessible when needed.

The aim is not to distract the user from the activity of cycling, but rather to support the user in a smooth and safe interaction with their surroundings. In this scenario, haptics do not serve as a disruptive alarm system, but as a silent and directional form of alert. Within this vision, it is also important that warnings are not generic, but contextually relevant. A future system should not communicate every potential threat in the same way, but should take into account context, urgency and the likelihood that the user has already detected the danger.

This shifts the role of the interface from ‘reporting everything’ to ‘only drawing attention to what is meaningful’.

4.3 DESIGN PRINCIPLES

The vision is translated into four design principles.

Cognitive relief through tactile dominance
Haptics are used as the primary channel for spatial warnings, so that visual and auditory cues remain available for the primary driving task.

Egocentric spatial mapping
The information is directly linked to the user's body. Left feels like left, behind feels like behind, etc., and through the mapping with head orientation, the feedback remains logical in relation to the current line of sight.

Evaluative early warning
The warning is provided early enough to give the cyclist room for assessment and anticipation, rather than merely provoking a startle response. The interface is therefore focused on alerting and situational awareness, not on forcing an immediate reflex.

Selective and context-aware alerts
A future B2X system should not automatically translate every event into an alert of equal severity. As more road users and objects become digitally connected, it will become necessary to filter alerts based on relevance, urgency and user context. In speculative future scenarios, this could mean that V2X warnings are linked to the user's attention or status information, so that a system reacts differently when a hazard has already been detected than when it has not. This could be made possible with broader developments in automotive driver monitoring, where gaze direction, eye opening and posture are already used to detect distraction or fatigue. (Bosch Mobility, n.d.; Chocksey, 2023)

4.4 SUCCESS CRITERIA

The success of this vision is assessed along three axes.

Intuitiveness
The user must be able to understand the haptic cue quickly and correctly, with minimal explanation.

Perceived safety
The interface must contribute to a greater sense of control and safety whilst cycling.

Acceptance in everyday use
The system must not be perceived as irritating or disruptive. Low annoyance and high willingness to use are essential to enable safety gains in practice.

In addition to these criteria, the vision implies a further quality requirement: **information discipline**. A system that is technically capable of detecting a great deal, but issues too many or too frequent warnings, undermines its own value (Figure 4.1). The quality of a future B2X system therefore depends not only on detection, but also on the extent to which it succeeds in transmitting information only at the moment when it is actually relevant to action.

PROJECT **SCOPE**

This chapter describes the scope of the graduation. The scope has been defined to clarify which elements were deliberately included or excluded, why these choices were made and what was achievable within the available timeframe of twenty weeks. At the end this chapter describes the involved stakeholders.

The scope of the project has been strongly influenced by the decision to work towards a **Proof of Value** rather than a full **Proof of Technology** within this graduation project. This means that the emphasis is not on demonstrating a complete V2X infrastructure, but on investigating whether directional haptic alerts can actually be useful, understandable and acceptable to elderly cyclists in a relevant usage context.

A key premise here is that the project lies at the intersection of **interaction design**, **product development** and **technical integration**. Although the core of the design question is closely linked to the discipline of Design for Interaction, this project was carried out within the **Integrated Product Design** master's programme. This means that the focus was not exclusively on user interaction, but also explicitly on the technical translation of the concept: building a functioning prototype, linking multiple subsystems and investigating which technical building blocks are required to make such interaction possible in the first place. Within this project, a conscious effort was therefore made to strike a balance between design content and technical implementation.

In addition, the scope was deliberately kept **dynamic** throughout the project. In the initial phase, the research focus was broad and ambitious, with several possible design directions. During the project, this scope was gradually narrowed down based on available time, technical feasibility and the question of which components were most relevant to actually investigate within the given timeframe. The scope is therefore not merely a pre-determined list, but also the result of design choices and prioritisation during the process.

Figure 4.1: AI generated image of donald duck cycling with an overload of feedback systems

5.1 IN THE SCOPE

This project covers all elements that directly contribute to investigating the central design question: how directional haptic feedback can be used to alert elderly cyclists to hazards in complex traffic situations at an early stage.

The first definition concerns the **target group**. The project specifically focuses on cyclist who are 60 years of age and older, since this group is over-represented in serious cycling accidents and in addition has specific physical and cognitive characteristics that are relevant to the design of safety interfaces. By selecting this target group, it is possible to test the interaction in a context where early, low-impact alerts potentially offer the greatest benefit.

The second definition concerns **early warnings**. The system is designed to facilitate the assessment of the situation by alerting the user in with enough time to assess potential threats. The design is not intended to enforce an immediate evasion or escape response but focuses on **communicating the location of the danger**. This is in line with the decision to approach the system as a warning layer rather than as an active emergency intervention.

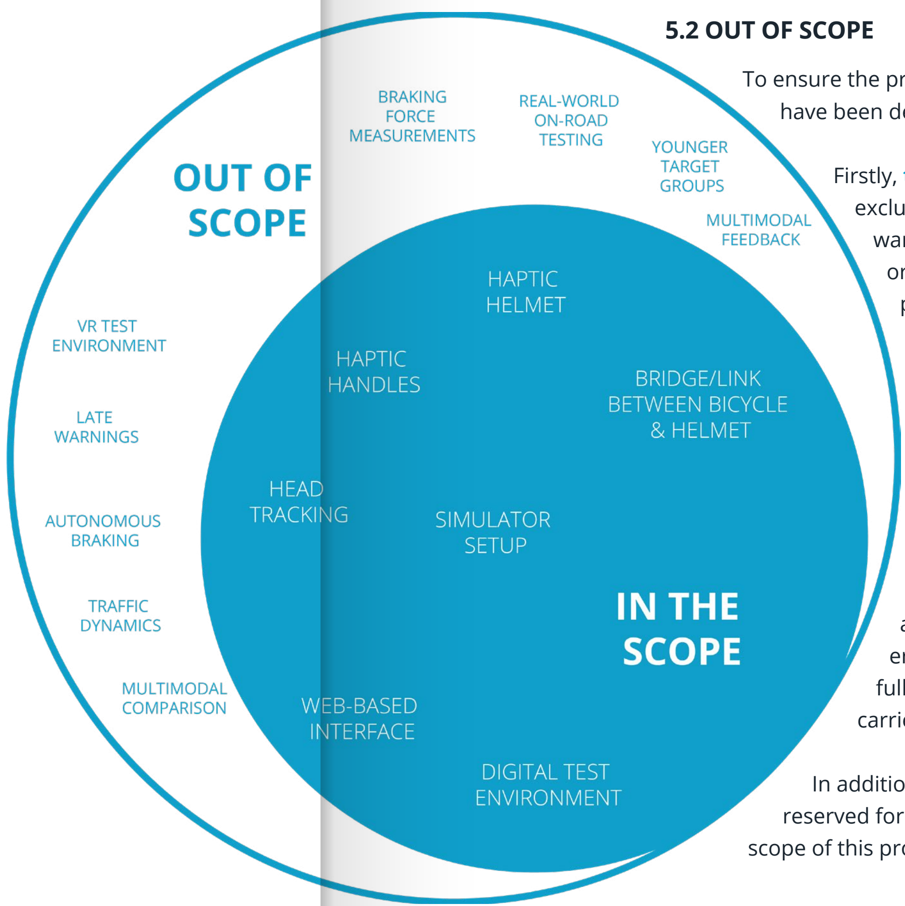
The selected **scenarios** also fall within this scope. The design focuses on two types of traffic situations: (1) low visibility situations, like a junction with a visual obstacle, and (2) situations where a road user is approaching from behind. These scenarios were chosen because they directly address the project's problem domain and can be successfully evaluated in a controlled simulator environment.

At the prototype level, the following components fall within the scope:

- **haptic helmet** with spatial haptic feedback;
- **head tracking** to support the link between orientation and feedback;
- **haptic handles** with vibration motors and brake buttons;
- **bridge/link between the bicycle and the helmet**, so that both systems can function as an integrated whole;
- **digital test environment** with simulated scenarios;
- **web-based interface** for playing back scenarios and linking the prototype components;
- **fixed-base simulator setup** for safe and controlled user testing.

The link between the bicycle and the helmet is a key building block within this project. The system demonstrates that the bicycle can function not only as a medium for interaction, but also as a technical platform upon which future smart helmet systems can be built. Examples include applications such as more reliable brake light and indicator functions, navigation or augmented reality within the helmet. By keeping more of the processing power and vehicle information on the bicycle, the helmet needs to process less data independently, which could make future helmet designs lighter and simpler.

Finally, the evaluation of the interaction also falls within the scope. The project focuses on investigating the comprehensibility, timing, perceived load and acceptance of the haptic interface within a simulated context. Both objective and subjective measurements are relevant in this regard.



5.2 OUT OF SCOPE

To ensure the project remains feasible within twenty weeks, various components have been deliberately excluded from the scope.

Firstly, **the implementation of a live V2X network** has been excluded from the scope. The project simulates traffic events and warnings, but does not develop a functioning V2X infrastructure or live communication between vehicles, infrastructure and the prototype. The integration of specific V2X hardware, such as the implementation of a complete V2X chip stack, has also been excluded. The focus is on user interaction and not on the full communication architecture or decision logic that determines which events are or are not reported to the user.

A **fully functional end product** is also outside the scope. The prototype has been developed as a research platform and not as a production-ready system. This means that aspects such as mass production, custom PCB manufacturing, product finishing and industrial integration have not been developed. Nor has the ergonomic and biomechanical optimisation of the helmet been fully investigated; in this project, the helmet functions primarily as a carrier of the haptic interaction.

In addition, various substantive developments have deliberately been reserved for future research. The following topics are therefore beyond the scope of this project:

- **late warnings** and evasion-oriented feedback;
- **autonomous braking** or other active vehicle interventions;
- **analogue braking force measurements**;
- **multimodal interaction strategies**, such as determining when visual, auditory or haptic feedback is most appropriate;
- the comparison between **early and late warnings** across different modalities;
- a fully developed **VR or game-based test environment**;
- **precise vehicle dynamics** and realistic driving models;
- **real-world on-road testing**;
- extension to a **younger target group**.

These components are not unimportant, but fell outside the core of the research question or could not be explored in sufficient depth within the time available. By keeping them outside the scope, this study was able to focus on the value of directional haptic alerts for elderly cyclists.

5.3 KEY TRADE-OFFS

A key trade-off in this project was the choice **between product quality** and **research value**. Rather than aiming for a fully developed, high-quality end product, this project opted for a prototype that is primarily suited to investigating interaction principles. This allowed attention to be directed towards components that were essential for the evaluation.

A second trade-off lay between **broad exploration** and **in-depth testing**. In the initial phase, the project had a broad, ambitious research direction with multiple possible system layers and multimodal interaction options. As the project progressed, the focus shifted towards a more in-depth exploration of a single specific direction, which was necessary in order to not only formulate a concept but also realise a working prototype and conduct an initial evaluation within twenty weeks.

A third trade-off concerns **realism versus controllability**. By opting for a fixed-base simulator and simulated events rather than real traffic situations with live V2X events, part of the reality has been deliberately simplified. At this stage of the research, it is important to keep the user tests safe, repeatable and measurable.

5.4 REFLECTION ON THE SCOPE

The scope of this project demonstrates that not all the original ambitions were achievable within the timeframe of twenty weeks. This is not a shortcoming of the project, but a logical consequence of the width and complexity of the subject. Specifically because the project spans mobility, interaction design, electronics, simulation and user research, it was necessary to make choices and explicitly postpone certain components

This reflection is important, as it means the project does not claim to offer a complete solution for connected cycling safety. Rather, its contribution lies in developing a working and testable building block within that larger system. By deliberately narrowing the scope to a haptic research platform for early warning, it has become possible to take a first step from abstract technological promise to concrete user value.

5.5 STAKEHOLDERS

Involved stakeholders are:

Older cyclists (aged 60+) and similar
As the primary stakeholder for this project, this group's acceptance of the design is highly important. Particular focus is placed on how they utilise, are comfortable with, and adjust to the design. Their feedback will be valuable in fine-tuning the design to meet their needs effectively.

Other road users
This project not only improves road safety for (older) cyclists, but also for other road users, such as cars and pedestrians, who rely on predictable cycling behaviour.

Coalition for Cyclist Safety
A coalition that creates innovative solutions that protect vulnerable road users.

Veilig Verkeer Nederland
An organisation that focuses on road safety education and stimulates people to take action to improve road safety.

Helmet and Bicycle designers and engineers
The reliability and quality of the implemented hardware and software are important for the project's success.

Manufacturers of (e-)bikes and helmets
These groups seek innovation and safety improvements for their products. The acceptance of the design of the helmet and handles is important. It must feel comfortable and be wearable.

Society, Health Organisations and Insurance Companies
These groups have a vested interest in the project's contribution to society. The fewer accidents there are, the less pressure there is on the healthcare system, and the lower healthcare costs will be.

CONCEPT **DIRECTION**

The concept behind this project is based on the idea that traffic information does not always have to be presented via screens or audio. The chosen approach is therefore a directional haptic interface that utilises two points of contact: the head and the hands.

The choice of these two locations is based on substantive considerations. The head is relevant because it is strongly linked to attention and spatial orientation, and research by Nukarinen et al., 2015, showed that this was perceived as a pleasant location for haptic feedback. Within this project, a helmet with **3D spatial haptic feedback** was therefore chosen, with multiple vibration motors positioned around the head. The underlying principle is similar to **spatial audio** (Figure 6.1) : just as sound can be spatially positioned around the head, haptic feedback can also be delivered directionally around the helmet. This allows the cyclist to sense the direction from which a threat is coming, without first having to look at a screen or interpret an auditory signal. An additional advantage of a helmet-based interface is that it builds on a safety device that is especially relevant for elderly cyclists (SWOV – Instituut voor Wetenschappelijk Onderzoek Verkeersveiligheid, 2024).

The hands constitute the second point of contact, as they are, in most cases, connected to the vehicle whilst cycling and are directly linked to steering control. Directional feedback in the handles can therefore serve as a supplementary or more locally perceptible warning. Together, the helmet and handlebar form a system in which spatial information can be conveyed to multiple parts of the body.

The connection between the helmet and the bicycle also makes it possible, in further development, to investigate **spatial effects**. An example of this is a **sweep** between the helmet and the Handles, whereby a threat is not only made perceptible directionally at a single location, but is experienced as a transition across multiple contact points. Within this project, such a sweep is therefore not seen as the basic principle of the concept, but as a possible extension of the interactive logic that builds on the technical bridge between helmet and bicycle.

This concept aligns with the earlier vision of a *'Sixth Sense'*. The interface should not be dominantly present, but should add an extra sensory layer at critical moments. As a result, the role of haptics shifts from a simple alarm signal to a carrier of spatial meaning.

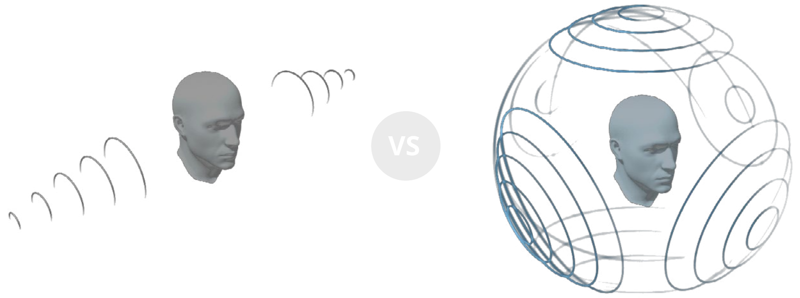
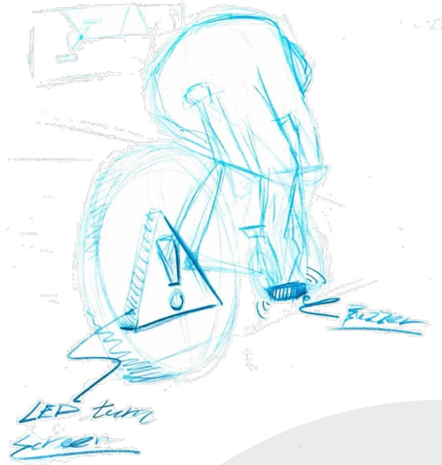
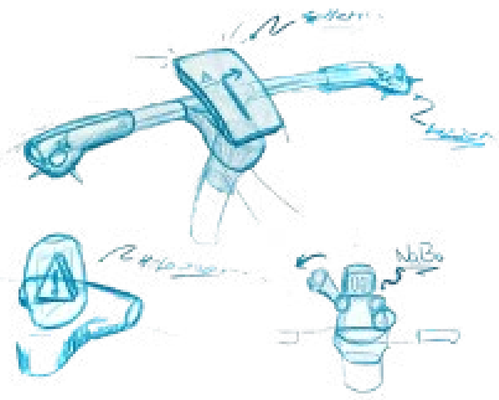
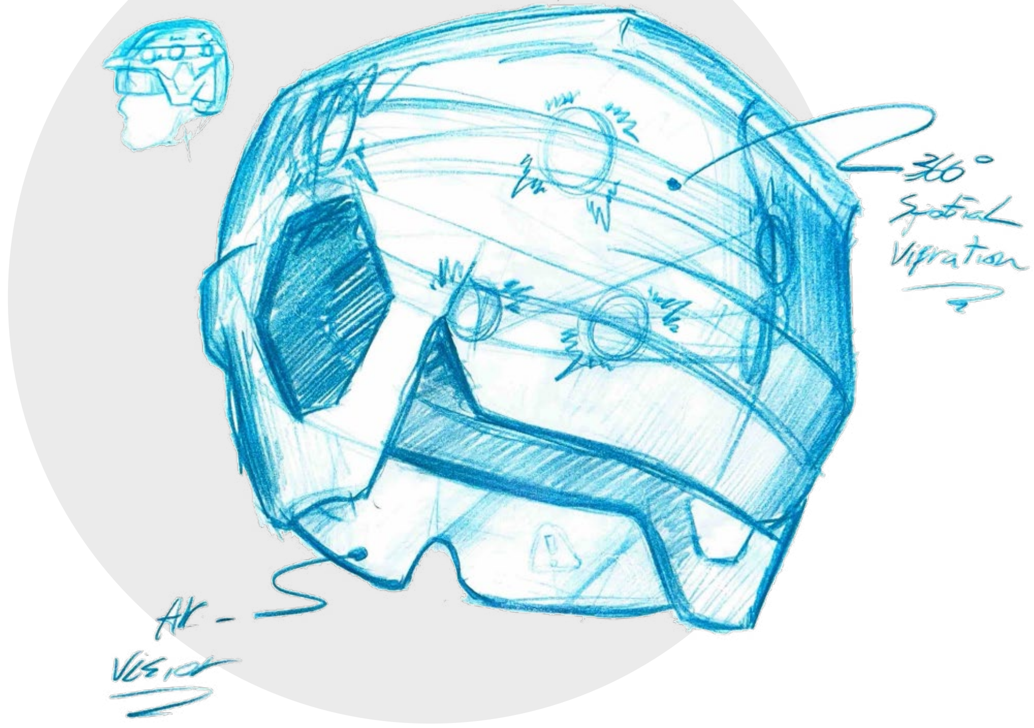


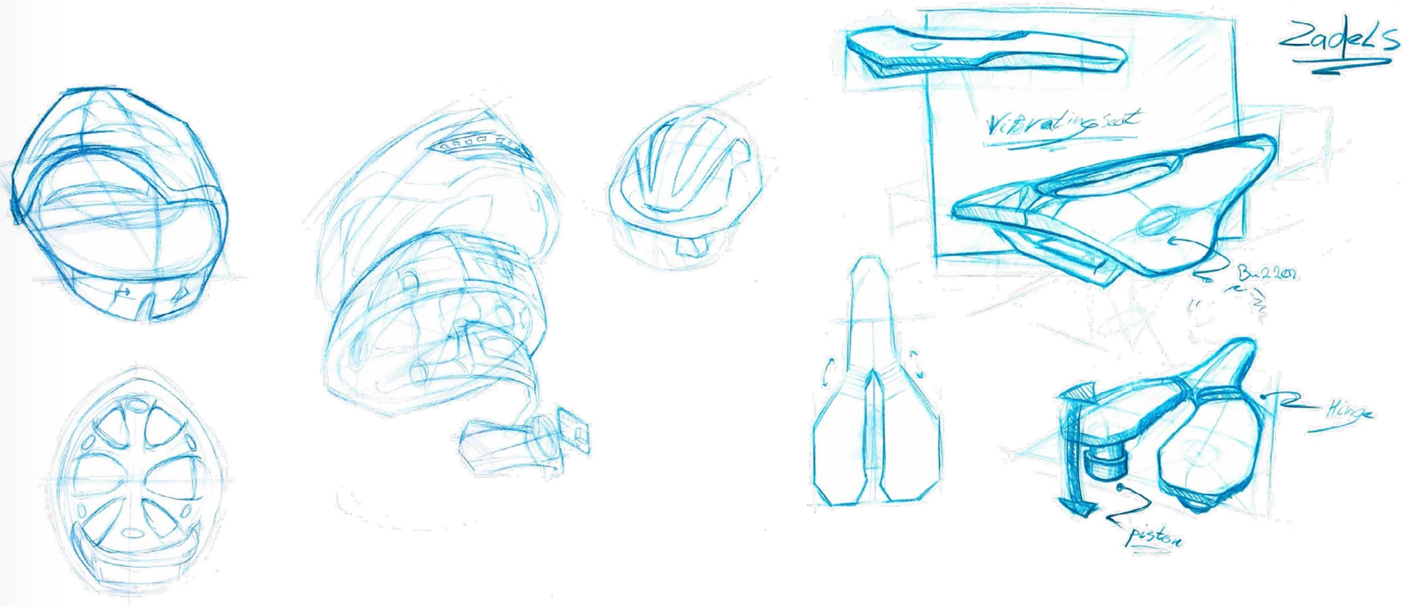
Figure 6.1: Stereo audio vs spatial audio
(https://docs.agora.io/en/video-calling/advanced-features/spatial-audio?platform=android)

6. CONCEPT DIRECTION









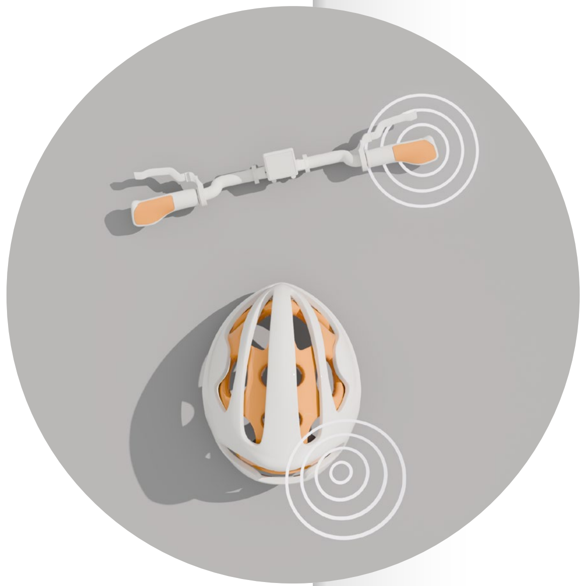
ELECTRONICS **DEVELOPMENT**

This chapter describes the technical design of the prototypes and the reasoning behind the selected components. As the system consists of several connected subsystems, development was not merely a matter of selecting individual components, but primarily of establishing a coherent architecture in which control, power supply, communication and physical integration are seamlessly integrated.

7.1 PROTOTYPE ARCHITECTURE

The prototype consists of two modules: 1] a **smart helmet** and 2] a set of **haptic handles**. Both modules have their own microcontroller, sensors and haptic control (Figure 7.1). Together, they make it possible to provide traffic information spatially across multiple contact points on the body.

The **helmet module** contains the 3D haptic feedback around the head and the sensors required for head tracking. The **handlebar module** provides directional vibrations in the handles and also registers the user's brake responses via buttons. The handlebar also function as an intermediary layer between the digital scenario environment and the helmet: scenarios and simulated V2X events are sent from the computer to the handles and then transmitted wirelessly to the helmet.



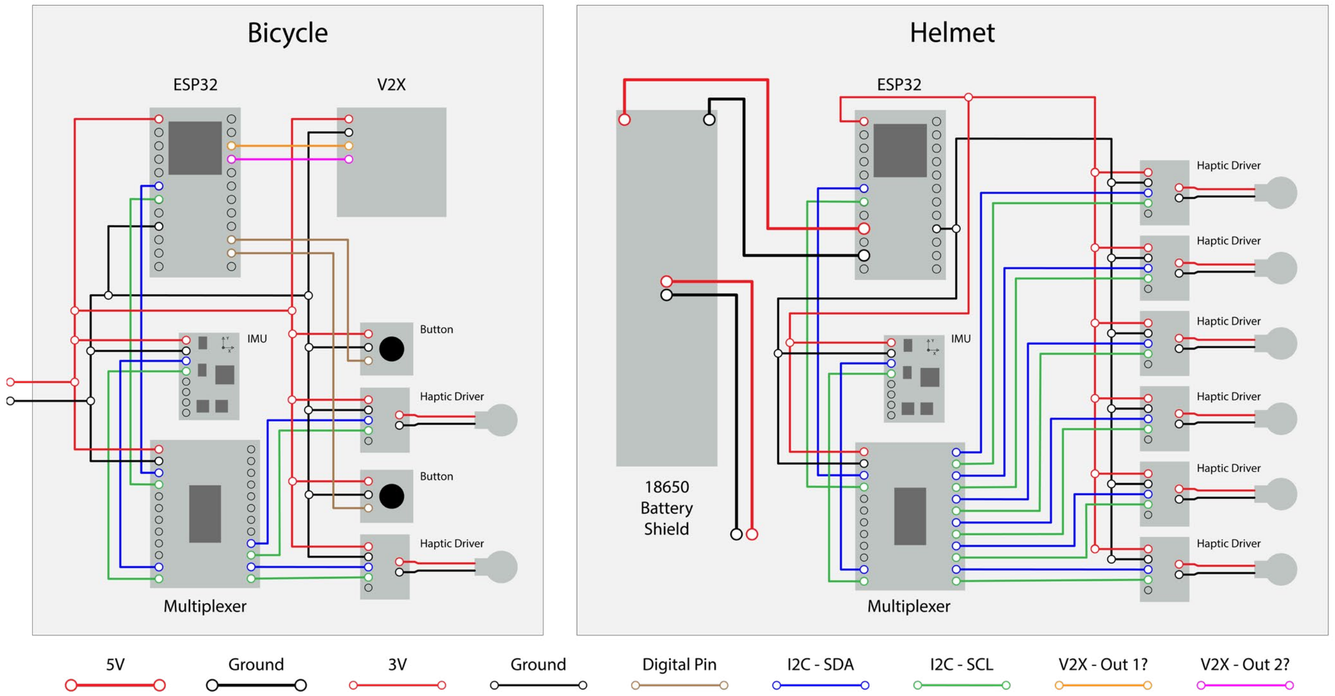


Figure 7.1: Electronics hardware design

7.2 COMPONENT SELECTION

The selection of components was determined by a combination of functional requirements, size, availability, supply voltage and power consumption. As both the helmet and the handles had to function as compact subsystems, it was necessary to select components that offered sufficient performance whilst also being suitable for a portable, battery-powered setup.

7.2.1 Microcontrollers

For the handles and the helmet, an **Arduino Nano ESP32** was selected (Figure 7.2). A microcontroller acts as a local control and processing unit in the prototype: it handles communication between the various system components, it analyses sensor data and controls the haptic outputs. Both practical and technical factors led to the selection of the ESP32.

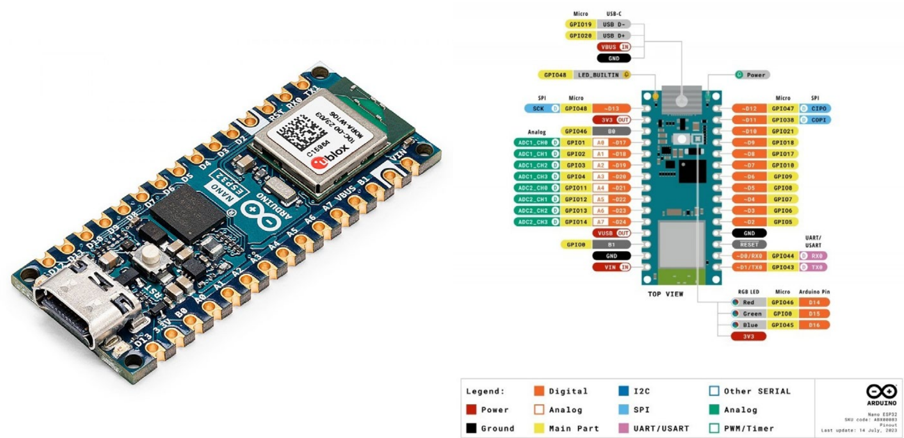


Figure 7.2: Arduino Nano ESP32 microcontroller
https://www.tinytronics.nl/en/development-boards/microcontroller-boards/arduino-compatible/arduino-nano-esp32-s3-seperate-headers](https://www.tinytronics.nl/en/development-boards/microcontroller-boards/arduino-compatible/arduino-nano-esp32-s3-seperate-headers

The chip combines a compact form factor with Wi-Fi, Bluetooth, USB-C, and ESP-NOW compatibility. For this project, the latter was especially crucial. Devices can communicate data directly without first establishing a conventional network connection thanks to Espressif's connectionless Wi-Fi communication protocol, ESP-NOW (Espressif Systems, n.d.). The direct connection between the helmet and the handles in this prototype was made possible by ESP-NOW, which allowed both subsystems to operate as separate modules while still having rapid information exchange.

7.2.2 Vibration motors

Seeed Studio Mini Vibration Motors were used as actuators (Figure 7.3). These coin-type motors form the physical output mechanism of the interface: they convert the system's digital signals into vibrations that can be felt on the head and in the handles.

The choice of these motors was based on their compact size and their suitability for integration into both wearable and handles. For the helmet, an actuator was required that could be positioned at multiple points around the head without making the system too heavy or bulky. For the handles, it was also necessary for the motors to be sufficiently perceptible within a limited installation space.

During the prototyping process, it became apparent that the performance of these motors depends not only on the electrical control but is also by their **orientation** and mounting. Because the rotating unbalanced weight moves internally around an axis, the direction of placement made a difference to how strongly and locally the vibration was actually felt. This has been explicitly taken into account in the latest version of the handles, whereas it had not yet been fully implemented in the helmet concept. This represents a clear learning point for further development.

Figure 7.3: Seeed Studio Mini Vibration Motors
https://nl.rs-online.com/web/p/power-motor-robotics-development-tools/1845122?srsltid=AfmBOooRiehc0cFWDr7le_lvkPVBcqRaOPAQYim-4TeNK2l2uSWcPsRGr

7.2.3 Haptic drivers

To control the vibration motors in a controlled manner, the **Adafruit DRV2605L Haptic Motor Controller** was chosen (Figure 7.4). This driver is specifically designed for haptic actuation and allows for more than simply switching a motor on and off. The chip supports predefined effects and enables, amongst other things, intensity build-up, short click signals and more controlled vibration profiles (Adafruit Industries, n.d.).

This choice was relevant because the project not only investigates whether a vibration is perceptible, but also how it is experienced as an attention signal. The DRV2605L enables more subtle and consistent feedback than direct on/off control. This allowed different vibration patterns to be tested more quickly without first having to programme all the effects at a low level.

The driver communicates via **I2C**. This offered advantages for compact integration, but also immediately raised a technical concern: all DRV2605L modules used have the same fixed I2C address. Consequently, they could not be controlled individually within the same subsystem without additional measures.

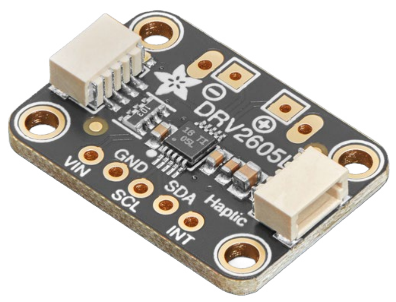


Figure 7.4: Adafruit DRV2605L Haptic Motor Controller
https://www.adafruit.com/product/2305

7.2.4 I2C multiplexer

To enable the separate use of multiple haptic drivers sharing the same I2C address, a **TCA9548A I2C multiplexer** has been incorporated into both the helmet and the handlebar system (Figure 7.5). This component allows multiple devices with identical addresses to be addressed via separate I2C channels.

Within this project, the multiplexer was therefore not an optional addition, but a direct consequence of the choice to use the DRV2605L drivers. Without this solution, it would not have been possible to control all haptic outputs independently, whilst precisely that individual control was essential for the directional output of the prototype. The multiplexer therefore made it possible to continue using the desired haptic libraries and effect profiles without having to fundamentally alter the system's architecture.

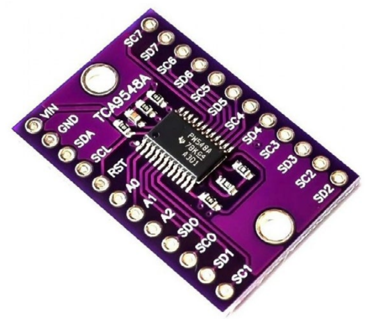


Figure 7.5: TCA9548A I2C multiplexer
https://www.tinytronics.nl/en/communication-and-signals/io-converters/i2c-multiplexer-tca9548a]

7.2.5 IMU modules

To measure orientation and movement, the MPU-6050 was initially used (Figure 7.6), followed later by a more advanced **GY-87 10DOF module** (Figure 7.7). An IMU has been installed in both the helmet and the handlebar.

In the handlebar system, the IMU is used to determine the direction of the bike in the real world. In the helmet, the IMU is used for **head tracking**: the system determines where the user is looking relative to the direction of the bike and can adjust the haptic mapping around the head accordingly.

During the project, it became apparent that the initial IMU solution suffered too much from **gyro drift**, meaning the mapping was not sufficiently stable. Consequently, a second version with an integrated **magnetometer** was implemented, so that the absolute orientation could be better corrected based on the Earth's magnetic field.

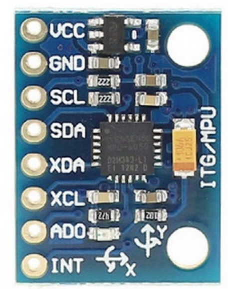


Figure 7.6: MPU-6050 IMU
https://www.tinytronics.nl/en/sensors/acceleration-rotation/mpu-6050-accelerometer-and-gyroscope-3-axis-module-3.3v-5v

Figure 7.7: GY-87 10DOF module IMU
https://elektronicavoorjou.nl/product/10dof-gy-87-sensor

7.2.6 Power modules and batteries

Both the helmet and the current test setup for the handles utilise an **Otronic 18650 battery holder with an integrated charger and a 5 V step-up module (USB-C)** (Figure 7.8), in combination with a **Samsung 18650 Li-ion battery** rated at 3400 mAh (Figure 7.9).

The choice of this module was based on several advantages. The holder has a USB-C connection, which is in line with market standards and simplifies charging for the user (Ministry of Economic Affairs and Climate Policy, 2023). In addition, the module contains an integrated **5 V step-up converter**, meaning no additional voltage converter needed to be added. Charge and discharge protection is also integrated, making the power supply safer and more practical for use within a portable prototype.

The final distribution of supply voltages across both subsystems is as follows:

- the battery holder provides a **5 V output** via the step-up converter;
- this 5 V is supplied to the **VBUS** of the Arduino Nano ESP32;
- the remaining electronics within the subsystem are powered via the **3.3 V output** of the microcontroller (Arduino).

This choice was based on both compatibility and simplicity of wiring. As several sensors and communication components operate at 3.3 V, it was possible to use a single central power supply per subsystem.

Figure 7.8: Otronic 18650 battery holder with an integrated charger and a 5 V step-up module (USB-C)
https://www.otronic.nl/nl/18650-batterijhouder-met-lader-en-5v-step-up-modul.html

Figure 7.9: Samsung 18650 Li-ion battery
https://www.otronic.nl/nl/samsung-18650-oplaadbare-batterij-36v-3400mah.html

7.2.7 Communication bridge

The digital test environment runs on a laptop or PC and handles the playback of scenarios, the simulation of V2X events and the management of test settings. The connection between this environment and the handle system is established via a **mini router (GL.iNet Slate 7)**.

In this setup, the router is used as a stable network bridge. Fixed IP addresses have been configured within the router for both the laptop and the Arduino of the handle system, so that both systems can consistently recognise each other without changing network configurations during testing. This helped to minimise connection issues during the user tests.

7.2.8 Brake input

Seeed Studio Grove Buttons were used to register responses in the handles (Figure 7.10). These buttons function as momentary on/off inputs and register when the user brakes.

The choice of these buttons was partly pragmatic, as they were already available within the project. At this stage of the project, the focus was not on accurately modelling braking force, but on recording whether and when the user responded to a warning. The buttons provided sufficient resolution for this purpose.

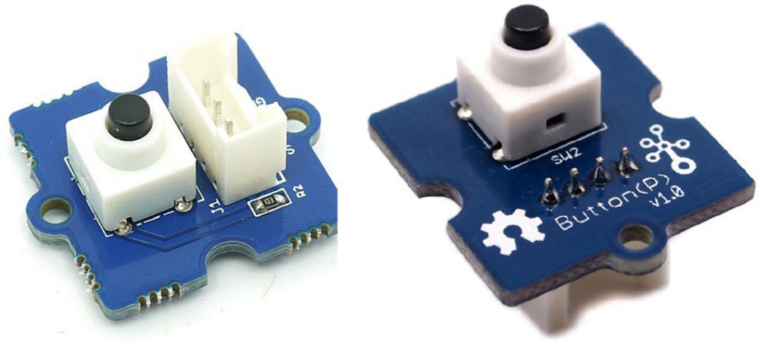


Figure 7.10: Seeed Studio Grove Buttons
https://wiki.seeedstudio.com/Grove-Button/

7.2.9 Wiring and physical integration

Wiring and physical integration also proved to be important design choices. Flexible single-core wire was used in the prototypes, as it is sufficiently flexible for installation in the portable and compact subsystems. Length, thickness and practical workability were key considerations here.

For the **handles**, the electronics are housed in a separate **prototype enclosure** with a physical on/off switch. **Two 5-core cables** run from this housing, one to each handle. This configuration serves, on the one hand, as a practical test setup, but has also been designed as a initial reason for product integration: in a final e-bike, these cables would run internally through the handlebar to the frame, whilst the electronics would be integrated into the e-bike itself.

7.3 POWER ARCHITECTURE

During the development of the prototype, a deliberate distinction was made between the **current test setup** and the **intended integration into a future e-bike context**.

For the **helmet module**, a fully independent battery-powered subsystem was chosen. This was necessary because the helmet must remain portable and must not be dependent on fixed cabling to the bicycle.

The situation is different for the handlebar module. In the current test setup, a separate 18650 power supply was also used for this, so that the entire system could function wirelessly and independently during testing. However, in the final product design, it makes more sense for the handlebar system to be powered directly from the **e-bike's battery**. As the handles are a physical part of the bicycle, this integration is the obvious choice. The current separate power supply should therefore be regarded as a prototype solution, not as the final design.

7.3.1 Indicative power budget of the helmet

An initial indicative power estimate has been made for the helmet based on typical component power consumption. This is based on:

- Arduino Nano ESP32: $I_{\text{ESP32}} \approx 120\,\text{mA}$
- 6 × DRV2605L: $6 \times 1\,\text{mA} = 6\,\text{mA}$
- GY-87 IMU: $I_{\text{IMU}} \approx 10\,\text{mA}$
- TCA9548A multiplexer: $I_{\text{MUX}} \approx 1\,\text{mA}$
- Step-up converter for self-consumption: $I_{\text{conv}} \approx 5\,\text{mA}$

The helmet contains six vibration motors, but typically only three are active at any one time during use. Assuming:

- Current per motor: $I_{\text{motor}} \approx 80\,\text{mA}$
- Number of motors active simultaneously: $n = 3$

The peak current of the motors is:

$$I_{\text{motor,peak}} = n \cdot I_{\text{motor}} = 3 \cdot 80 = 240\,\text{mA}$$

However, the motors are only active for a short time. With an activation duration of 2 seconds every 120 seconds, the duty cycle is:

$$D = \frac{2}{120} = 0.0167$$

The average motor current is then:

$$I_{\text{motor,avg}} = I_{\text{motor,peak}} \cdot D = 240 \cdot 0.0167 \approx 4\,\text{mA}$$

The total average power consumption of the helmet module is therefore:

$$I_{\text{helmet}} = I_{\text{ESP32}} + I_{\text{DRV}} + I_{\text{IMU}} + I_{\text{MUX}} + I_{\text{conv}} + I_{\text{motor,avg}}$$

$$I_{\text{helmet}} = 120 + 6 + 10 + 1 + 5 + 4 = 146\,\text{mA}$$

With a battery capacity of:

$$C_{\text{bat}} = 3400\,\text{mAh}$$

is the theoretical service life:

$$t_{\text{ideal}} = \frac{C_{\text{bat}}}{I_{\text{helmet}}} = \frac{3400}{146} \approx 23.3\,\text{uur}$$

As the 5 V step-up converter is not lossless, an efficiency of approximately:

$$\eta = 0.85$$

has been taken into account.

The effective usable capacity then becomes:

$$C_{\text{eff}} = \eta \cdot C_{\text{bat}} = 0.85 \cdot 3400 \approx 2890\,\text{mAh}$$

This results in a more realistic operating time of:

$$t_{\text{real}} = \frac{C_{\text{eff}}}{I_{\text{helmet}}} = \frac{2890}{146} \approx 19.8\,\text{uur}$$

The realistic battery life of the helmet is therefore around: $t_{\text{helmet}} \approx 18\text{–}20\,\text{uur}$

7. ELECTRONICS
DEVELOPMENT

7.3.2 Peak current of the helmet

In addition to average power consumption, peak currents are also relevant. When three motors are active simultaneously and the ESP32 experiences a communication peak, the instantaneous current demand can rise to approximately:

$$I_{\text{peak}} \approx 240 + 400 + 10 = 650\,\text{mA}$$

where 400 mA represents a typical communication peak of the ESP32. The selected Samsung 18650 cell, with a maximum current capacity of 8 A, can deliver this peak without any issues.

7.3.3 Indicative power budget of the handlebar module

A similar calculation applies to the handlebar module, but with fewer actuators and drivers. The system comprises:

- 1 × Arduino Nano ESP32: $I_{\text{ESP32}} \approx 120\,\text{mA}$
- 2 × DRV2605L: $2\,\text{mA}$
- 1 × GY-87 IMU: $I_{\text{IMU}} \approx 10\,\text{mA}$
- 1 × TCA9548A: $I_{\text{MUX}} \approx 1\,\text{mA}$
- Step-up converter loss: $5\,\text{mA}$

For the two vibration motors:

$$I_{\text{motor,peak,h}} = 2 \cdot 80 = 160\,\text{mA}$$

With the same duty cycle of:

$$D = 0.0167$$

the average motor current becomes:

$$I_{\text{motor,avg,h}} = 160 \cdot 0.0167 \approx 2.7\,\text{mA}$$

Thus, the total average current consumption of the handlebar module is:

$$I_{\text{handlebar}} = 120 + 2 + 10 + 1 + 5 + 2.7 \approx 140.7\,\text{mA}$$

rounded to:

$$I_{\text{handlebar}} \approx 141\,\text{mA}$$

The average electrical power at 5 V is then:

$$P_{\text{handlebar}} = U \cdot I = 5 \cdot 0.141 = 0.705\,\text{W} \quad P_{\text{handlebar}} \approx 0.7\,\text{W}$$

7.3.4 Indicative impact on e-bike range

For the final product vision, what is particularly relevant is what this means when the handles are powered by the e-bike battery. For a typical e-bike battery of, for example:

$$E_{\text{bike}} = 500\,\text{Wh}$$

and an additional continuous load of:

$$P_{\text{handlebar}} \approx 0.7\,\text{W}$$

the theoretical operating time of this subsystem alone is:

$$t = \frac{E_{\text{bike}}}{P_{\text{handlebar}}} = \frac{500}{0.7} \approx 714\,\text{uur}$$

Even when conversion losses and a slightly higher practical power of approximately 0.8 W are taken into account, this remains:

$$t = \frac{500}{0.8} = 625\,\text{uur}$$

With typical e-bike energy consumption of approximately:

$$8\text{–}12\,\text{Wh/km}$$

the additional load on the handlebar system therefore remains very small in relation to the energy consumption of the drive itself. The impact on the e-bike's range can therefore be considered negligible.

7.3.5 Implications for future integration

The chosen energy architecture thus supports not only the current prototype but also the project's broader system vision. The helmet can remain independent, lightweight and portable, whilst the handles, in a future product implementation, make logical use of the bicycle's energy infrastructure. This makes the bicycle not only a carrier of mechanical components but also a technical platform for power supply, communication and future smart functions.

7.4 COMMUNICATION AND LATENCY CONSIDERATIONS

The connection between the computer, handles and helmet has proven sufficiently stable in the current setup for the user tests carried out. No major latency issues were encountered during testing. At the same time, the end-to-end delay between the scenario, handles and helmet has not yet been precisely quantified in this project phase.

This is for now out of the scope of this project. However, a more accurate validation of the system delay could, for example, be carried out using a slow-motion or high-speed camera, so that the exact time difference between event trigger, haptic activation and user response can be measured.

7.5 REFLECTION ON ELECTRONICS DEVELOPMENT

The development of the prototype made it clear that component selection and system architecture are directly linked to the quality of the interaction. Key lessons learnt included the influence of motor orientation on the perceptibility of vibrations, the need for magnetometer-based correction to limit drift in the tracking, and the fact that the choice of a particular haptic driver had direct consequences for the rest of the electronics architecture, such as the use of an I2C multiplexer.

The prototype thus demonstrates not only an interaction concept, but also an initial technical system model for future smart cycling solutions in which wearable and vehicle-mounted components work together. It is precisely this link between the bicycle and the helmet that forms a key building block for further development within this project.

PROTOTYPING **HANDLEBAR**

This chapter describes the physical development of the handle prototype. It covers the digital workflow, the electronics integration, the handle prototype, the material exploration and the reflection on the process.

In addition to the electronic development, the physical realisation of the prototype also played an important role, particularly with regard to the handles. It was precisely here that form, installation space, material behaviour and haptic performance came together directly. The development of the handle prototype was therefore not only a technical realisation of the electronics, but also an iterative design process in which multiple versions were modelled, printed and tested.

8.1 DIGITAL WORKFLOW: SCAN, MODEL AND PRINT

For the physical development of the handle prototype, a workflow involving 3D scanning, modelling in Blender and 3D printing was used. Various electronic components were scanned using a Creality Otter Lite, so that their dimensions and shape could be used as a reference in Blender. This allowed for faster design work around the actual components.

The transition from scan to usable model proved to be anything but straightforward. The initial scans were often heavy and difficult to process, mainly due to high mesh resolutions. Consequently, scans had to be cleaned up and simplified before they could be used effectively in Blender (Figure 8.1). In this project, 3D scanning thus became not only a tool for capturing shapes, but also an iterative process of selecting, simplifying and adapting them for product development. As this approach was new to the researcher, it simultaneously constituted an important learning process and the development of a new skill set within the project.

Within Blender, the handles were then further modelled manually. The scans were not used as the final form, but primarily as a spatial reference for the installation of electronics, cables and mounting points. After modelling, the parts were exported as STL files and prepared for 3D printing.

Figure 8.1: 3D scan of a handlebar in Crealityscan application (before cleaning up the mesh)

8.2 EARLY PROTOTYPING AND ELECTRONICS INTEGRATION

In the initial iterations, the focus was primarily on fit and electronics integration. The handles have to accommodate the vibration motor, the haptic driver, cabling and mounting to a temporary handlebar. At the same time, the design had to be sturdy enough to withstand multiple test cycles.

The basic shape of the handle was derived from a handle previously designed by MODYN. By building on an existing MODYN handle design, the physical prototyping process could focus on integration, rather than completely redesigning the basic ergonomics and design language of the handle.

During this phase, it quickly became clear that the handlebar is not merely a carrier of electronics, but also a mechanical component that directly influences the quality of the haptic experience.

8.3 ITERATIVE DEVELOPMENT OF THE HANDLEBAR PROTOTYPE

As the prototype was further developed, the focus shifted from pure installation to the quality of **vibration transmission**. The central question thus became not only whether everything would fit inside the handle, but also how the feedback would ultimately be felt within the handle.

A key insight from the iterations was that the perceptibility and directional experience of the haptic signals depend not only on the electronic control system, but are also strongly influenced by the mechanical design of the handle. In particular, the risk of vibrations spreading undesirably through the handle proved to be a key concern. This led to the need to optimise not only the position of the motor and driver, but also the material composition of the handle itself.

During these iterations, various adjustments were investigated, including changes to wall thickness, internal dimensions, grip structure and printing settings (Appendix A). The extent to which these changes contain vibrations locally or, conversely, allow them to leak further into the handlebar was also examined

8.4 MATERIAL EXPLORATION

During the development of the handles, it became apparent that the choice of material has a direct influence on haptic performance. Stiffer materials are beneficial for dimensional stability and assembly, but also allow vibrations to spread more easily through the handlebar. As a result, the feedback can feel less localised and less directional.

Based on this observation, **TPU** was also tested. The idea behind this was that a softer, more damping material would be better able to contain the vibrations within the handle itself, rather than allowing them to be transmitted uncontrollably to the handlebar. However, the first TPU iterations proved to be relatively hard, leading to the expectation that vibrations would still leak through the handlebar too much. This led to further exploration of shape, wall thickness and material composition.

8.5 REFLECTION ON PHYSICAL PROTOTYPING

The development of the handles demonstrated that the physical form of the prototype cannot be viewed seperately from the quality of interaction. In this project, 3D printing was therefore not merely a manufacturing method, but also a research tool. Each new version revealed how changes in geometry, material, motor placement and assembly directly affect the tactile quality and directional experience of the haptic feedback.

In this way, the handle development process demonstrates that the development of a haptic interface is not solely an electronic challenge. It was the combination of digital modelling, physical iteration and material experiments that proved essential in transforming a technically functioning signal into a usable physical experience.

SOFTWARE & SYSTEM **ARCHITECTURE**

This chapter describes the software and system architecture of the prototype. The aim of this chapter is to clarify how the different subsystems are connected and how information flows through the complete system. To support this, the architecture is presented through a series of block diagrams that together explain the overall system structure, trial logic, communication flow and directional mapping process.

The proposed system consists of a web interface, a central server, a Gateway ESP32, Node A on the bicycle, and Node B in the helmet. The web interface is used to configure trials, trigger cues and inspect measurement results. The server manages the overall trial logic, maintains the system state and stores the experimental data. The gateway forms the communication bridge between the central software environment and the local embedded network. Within the embedded layer, Node A acts as the primary bicycle node. It controls the handlebar feedback, processes user input, and forwards directional information to Node B. Node B then maps this information to the appropriate haptic location on the helmet.

Within the proposed architecture, Node A provides the directional reference for the helmet subsystem by transmitting both the current bicycle heading and the simulated V2X hazard direction to Node B. Node B compares this information with the orientation of the helmet and determines the relative direction of the hazard with respect to the rider's head. This makes it possible to present directional hazard information not only through the handlebar, but also as spatially meaningful haptic feedback around the helmet.

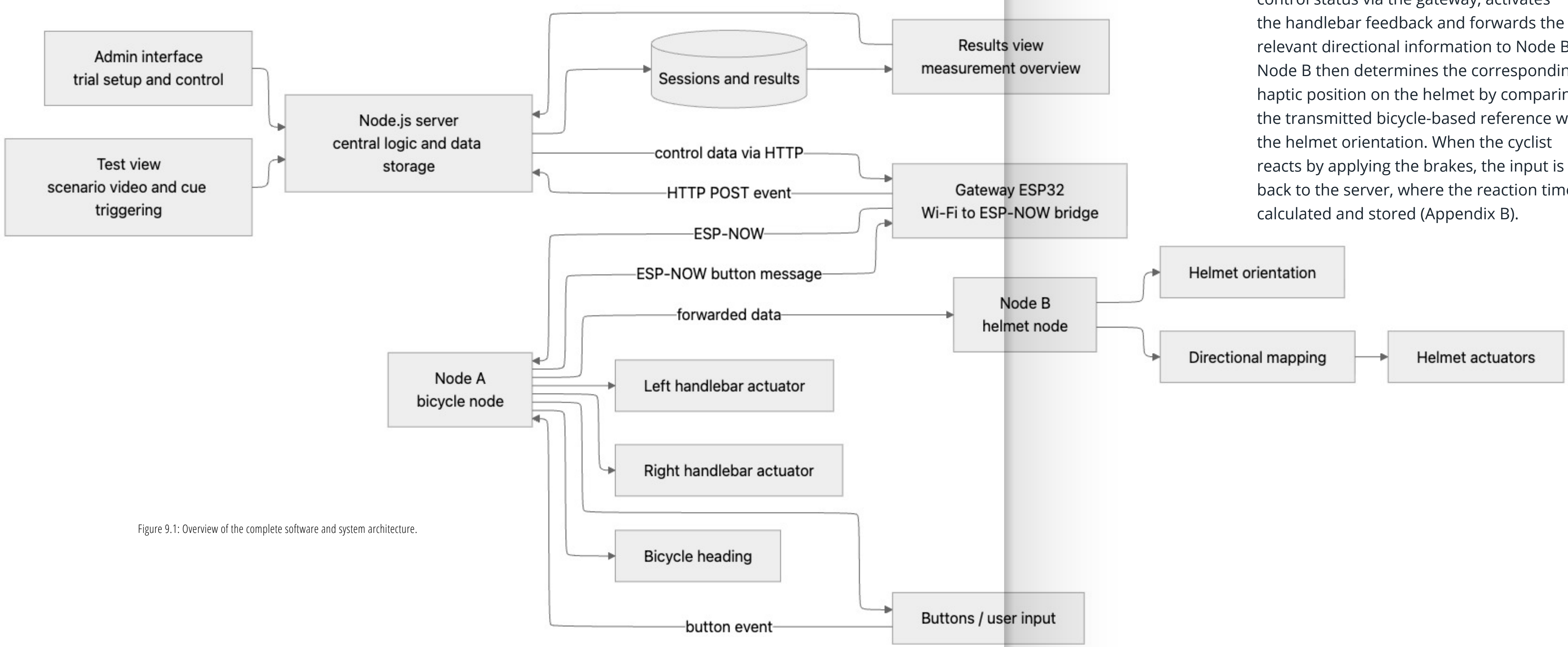


Figure 9.1: Overview of the complete software and system architecture.

Figures 9.1 to 9.6 present the architecture from different perspectives. Together, these figures explain the overall system configuration, the sequence of events during a trial, the division into software layers, Node A's functional role, the directional transformation from bicycle spatial heading to helmet spatial heading, and the communication structure between the various subsystems.

9.1 OVERALL SYSTEM ARCHITECTURE

Figure 9.1 shows the overall architecture of the proposed system. The server functions as the central control point and is responsible for trial management, cue activation and result storage. The gateway retrieves the relevant control data from the server and transmits it to Node A via ESP-NOW. Node A serves as the principal embedded node on the bicycle. It drives the handlebar actuators, reads the rider input, and forwards directional data to Node B. Node B then performs the final directional mapping for the helmet actuators.

9.2 TRIAL SEQUENCE

Figure 9.2 summarises the logic of a single trial. After the trial parameters have been defined, the selected scenario video is loaded and played. Once the predefined cue frame is reached, the server activates the cue. After that, Node A receives the updated control status via the gateway, activates the handlebar feedback and forwards the relevant directional information to Node B. Node B then determines the corresponding haptic position on the helmet by comparing the transmitted bicycle-based reference with the helmet orientation. When the cyclist reacts by applying the brakes, the input is sent back to the server, where the reaction time is calculated and stored (Appendix B).

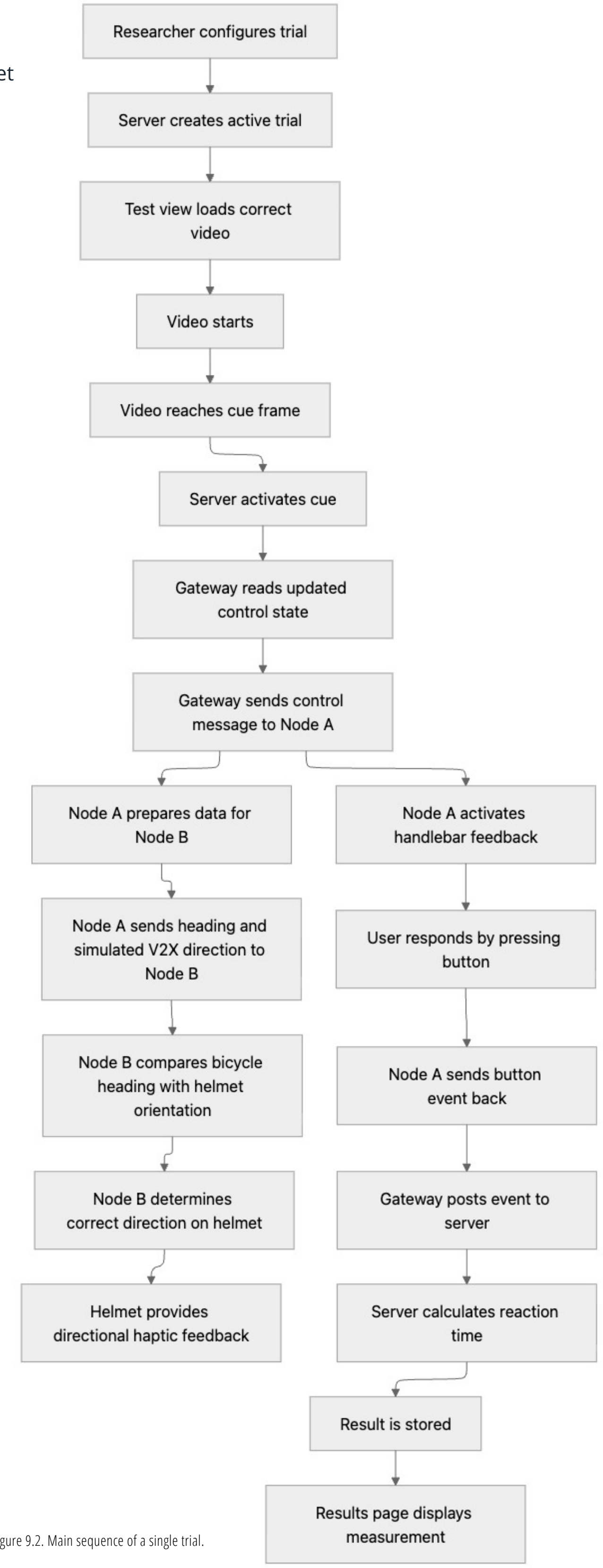


Figure 9.2. Main sequence of a single trial.

9.3 LAYERED SYSTEM STRUCTURE

The architecture can be divided into three principal layers:

- Web layer

The web layer supports trial configuration, scenario playback and result inspection.

- Server layer

The server layer manages the experimental logic and records the resulting data.

- Embedded layer

The embedded layer is responsible for the physical execution of the haptic behaviour. Within this layer, Node A operates as the primary bicycle node, while Node B functions as the helmet-specific output node (figure 9.3).

9.4 FUNCTIONAL ROLE OF NODE A

Node A fulfils a central role within the proposed architecture. On the one hand, it controls the handlebar actuators according to the active cue and the hazard direction. On the other hand, it acts as the reference node for the helmet subsystem by forwarding both the bicycle heading and the simulated hazard direction to Node B. In addition, Node A captures the rider response through the button input and returns this event to the gateway (figure 9.4).

9.5 DIRECTIONAL MAPPING FROM BICYCLE TO HELMET

Figure 9.5 illustrates the intended directional mapping process. Node A provides the bicycle heading together with the simulated V2X hazard direction. Node B compares this information with the orientation of the helmet and transforms the hazard direction into the correct relative position around the rider's head. This approach ensures that the helmet feedback remains spatially meaningful, even when the rider changes head direction (figure 9.5).

9.6 COMMUNICATION STRUCTURE

The communication structure is divided into two domains. Between the laptop environment and the server, communication is handled through HTTP. Within the embedded system, communication is performed via ESP-NOW. In this architecture, Node A acts as the first local receiver of the control data and forwards the relevant directional information to Node B (figure 9.6).

9.7 CONCLUSION

The proposed software and system architecture follows a layered and modular structure. The web interface supports trial configuration and result visualisation, the server manages the experimental logic and data storage, the gateway connects the software environment to the embedded network, and Nodes A and B jointly produce the haptic output. Within this architecture, Node A provides the bicycle-based directional reference, while Node B translates that reference into the correct haptic direction on the helmet. As a result, the system enables simulated hazard information to be communicated not only as a warning signal, but as spatially structured haptic guidance for the rider.

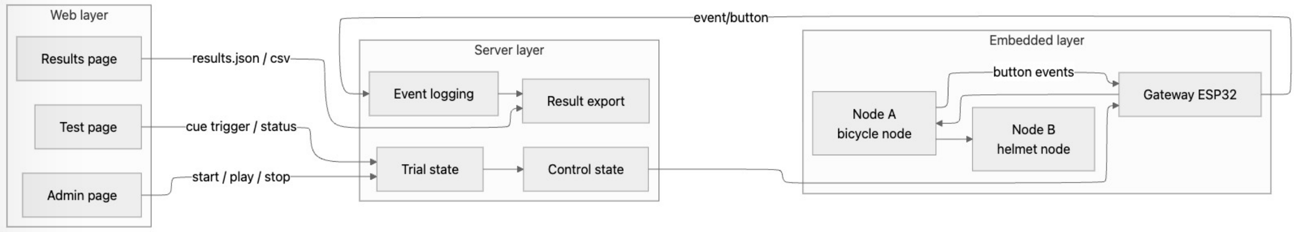


Figure 9.3. Division of the system into web, server and embedded layers.

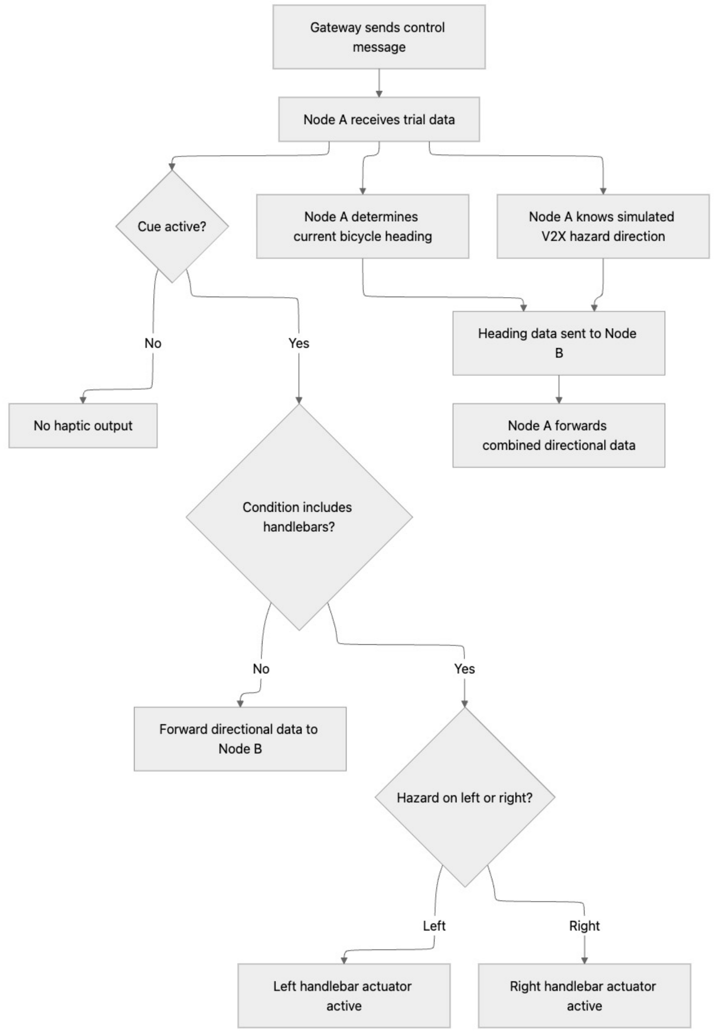


Figure 9.4. Functional role of Node A within the system.

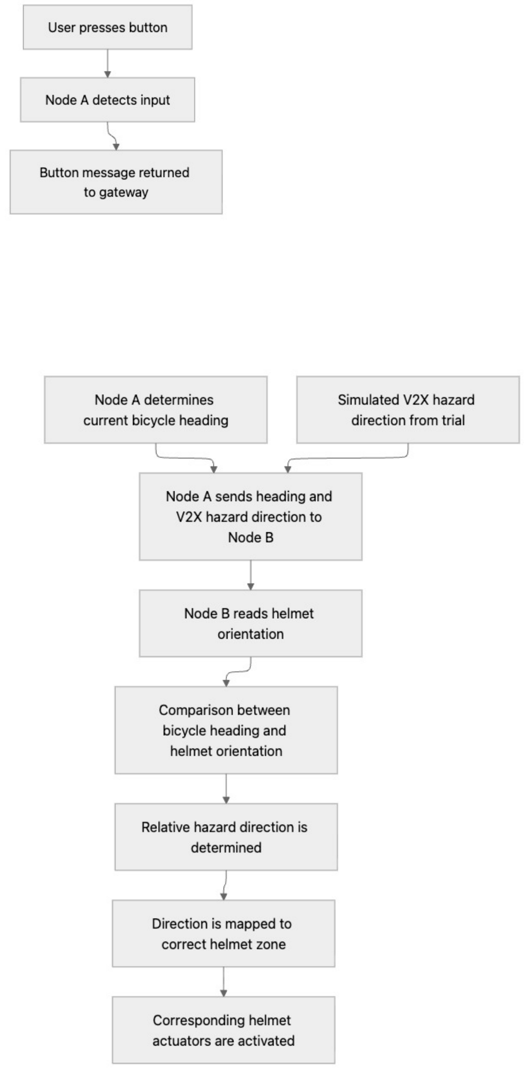


Figure 9.5. Directional transformation from bicycle reference frame to helmet reference frame

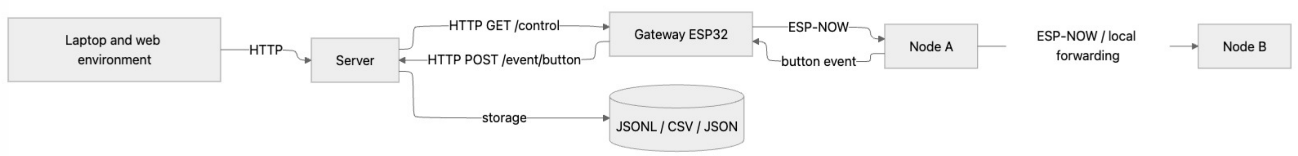


Figure 9.6. Communication path between the software environment and embedded subsystems.

USER **TESTING**

This chapter describes the user evaluation of the directional haptic warning system developed in this graduation project.

The purpose of the study was to examine whether directional haptic feedback, delivered through vibrating handles and a vibrating helmet, would be experienced as an acceptable interaction modality in a desktop-based simulated cycling context. The evaluation of the project focused on perceived workload, usefulness, satisfaction, clarity, perceived safety, and irritation. In addition, supportive behavioural measures were collected in order to examine how participants interpreted the warnings and how these warnings influenced response behaviour (Appendix N).

The study was designed as a small-scale mixed-method user evaluation (Appendix H). Quantitative questionnaire data were combined with qualitative interview data, researcher observations, and assisting behavioural logs. The emphasis was not on large-scale behavioural performance testing, but on whether the prototype showed sufficient promise in terms of interaction quality and user acceptance to justify further development.

10.1 HYPOTHESES

The following hypotheses were formulated for this user evaluation study:

H0 (Main hypothesis) Directional haptic feedback via vibrating handles and a vibrating helmet will be experienced as an acceptable interaction modality, characterised by acceptable mental workload, positive perceived usefulness and satisfaction, and generally positive evaluations of clarity, perceived safety, and low irritation.

H1 (Workload) Directional haptic feedback via vibrating handles and a vibrating helmet will be experienced as involving an acceptable level of mental workload.

H2 (Usefulness) Directional haptic feedback via vibrating handles and a vibrating helmet will be evaluated positively in terms of perceived usefulness.

H3 (Satisfaction) Directional haptic feedback via vibrating handles and a vibrating helmet will be evaluated positively in terms of perceived satisfaction.

H4 (Clarity and interpretability) Participants will generally experience the directional haptic feedback as clear and understandable.

H5 (Safety and irritation) Participants will generally experience the directional haptic feedback as supportive for perceived safety and low in irritation.

10. USER TESTING

10.2 STUDY DESIGN

A within-subject mixed-method design was used. Each participant experienced all feedback conditions within a single session. This design was selected because it allowed each participant to form an informed judgement of the prototype after directly experiencing both haptic modalities and the no-feedback condition.

The study was primarily concerned with the perceived quality and acceptability of directional haptic feedback rather than extensive behavioural optimisation. For that reason, the trial block was deliberately kept small. The scenarios were intended to provide sufficient experience with the prototype for reflection and evaluation, while keeping the session manageable and avoiding unnecessary fatigue.

10.3 TEST SETUP AND APPARATUS

The evaluation was conducted in a seated desktop-based simulation setup. Participants remained seated in front of a monitor, wore the helmet prototype, and placed their hands on the handlebar prototype. The simulated scenarios were shown on-screen from the perspective of a cyclist. During selected trials, directional haptic warning cues were delivered either through the helmet or through the handles. Participants were informed that the video would continue regardless of whether they braked, meaning that braking did not influence the scenario itself. Their responses were therefore used primarily to understand how they interpreted the warnings and how they reacted to them naturally.

The helmet prototype delivered spatial vibration cues around the head and used head tracking to maintain the spatial relation between hazard direction and head orientation. The handlebar prototype delivered directional vibration cues through the left or right handle. Both systems were intended to communicate the direction from which a possible hazard was approaching. The procedure instructed participants to respond as naturally as possible and, if they felt it was necessary, to brake in a way they would normally brake on a real bicycle. The procedure also emphasised that there was no single correct braking strategy, as the study also was interested in how the warning was interpreted and how participants responded spontaneously.

10.4 FEEDBACK CONDITIONS

Three feedback conditions were tested:

1. no feedback;
2. handlebar only;
3. helmet only.

The no-feedback condition functioned as a baseline against which the two haptic conditions could be interpreted. The helmet and handlebar conditions allowed comparison between the two feedback modalities in terms of clarity, perceived usefulness, satisfaction, and influence on natural response behaviour. The study design deliberately focused on making certain that participants could meaningfully experience both haptic modalities rather than on comparing a large number of additional conditions.

10.5 SCENARIOS

Three tested scenarios were selected to reflect relevant moments from the intended cycling context, falling under two scenario types: (1) alerting in conditions of limited visibility and (2) alerting during physically demanding control actions. The selected scenarios are directly derived from the problem space in Chapter 3.

Scenario A: Intersection with visual obstruction

In the first scenario, the participant approaches a traffic situation in which a conflict arises with a party that is initially outside the direct line of sight. Visual information is still limited at the moment of warning, making the participant heavily reliant on haptic alerts. This scenario is intended to investigate whether directional haptics can help focus attention on a relevant hazard location before it is fully visible.

Scenario B: Overtaking from behind

In the second scenario, another road user approaches the cyclist from behind, for example whilst overtaking. This scenario has been included because the classic response in such situations is often a shoulder check or a reaction to an auditory cue, whereas this action can be physically demanding for elderly cyclists or cause instability. Here, this project investigates whether haptic feedback can serve as an early warning signal without the cyclist first having to make a significant head or torso rotation.

Together, these scenarios form a functional translation of the design context into testable interaction moments. They are not intended to represent the full complexity of real traffic, but as a targeted test of the chosen design principle. They formed a focused and manageable set of representative events through which the user experience of the proposed warning system could be evaluated.

The main trial block, therefore, consisted of three selected traffic events:

1. a car approaching from the front-left;
2. a car approaching from the front-right;
3. a cyclist overtaking from the rear-left.

For each event, feedback was presented either through the helmet, through the handles, or not at all. In the intersection scenarios, the handlebar cues were localised to the left or right side accordingly, and the helmet cues consisted of corresponding front-left or front-right local pulses. In the overtaking scenario, the handlebar cue was presented as a left-pulsing signal and the helmet cue as a left sweep across the helmet.

The overtaking scenarios should be interpreted cautiously, as they did not represent overtaking from multiple directions or by different traffic actors, but only a single rear-left overtaking event by a cyclist.

10.6 PARTICIPANTS AND RECRUITMENT

The intended participant group consisted primarily of cyclists aged 60 years and older, because the project focuses on elderly cyclists. However, the recruitment plan already allowed for the inclusion of participants aged 40 years and above when necessary, while noting that such findings should be interpreted with care in relation to the 60+ target group. A further practical inclusion criterion was that participants had to be able to wear the available medium-sized helmet prototype comfortably enough for the haptic feedback to be experienced properly. The user test plan, therefore, defined the following inclusion and exclusion criteria:

Inclusion criteria:

- adult status
- voluntary participation
- adequate helmet fit
- and the ability to complete the session in a seated indoor setup

Exclusion criteria:

- poor helmet fit
- strong discomfort and strong sensitivity to vibration
- inability to provide informed consent

Data collection initially took place during two test days at Gazelle. Recruitment in this visitor-based context progressed more slowly than anticipated, resulting in five completed sessions. In order to reach the intended sample size, additional locations were visited, using a portable version of the same desktop-based test setup. These additional sessions were conducted in informal community-based settings. Across all locations, participants completed the same seated desktop-based simulation procedure and the same random sequence of events, questionnaires, observations, and post-test interview questions.

In total, 13 participants completed the study. The sample should therefore be regarded as a practical convenience sample rather than a tightly controlled recruitment sample.

10.7 PROCEDURE

Each participant first received an explanation of the study and signed the informed consent form (Appendix G]). A participant ID was then assigned and used on all non-consent materials (Appendix H). Participants subsequently completed a short background questionnaire (Appendix J) and a pre-test Van der Laan acceptance scale (Appendix K) based on their first expectation of the system. The participant information sheet (Appendix I) stated that the study concerned the evaluation of the prototype rather than the testing of the participant and that participation was voluntary.

Next, the helmet was fitted and calibrated. Participants were asked to look forward while the system was reset and calibration was started. After calibration, participants completed a short practice phase consisting of four practice trials. These practice trials were not included in the final analysis and were intended to familiarise participants with the setup, reduce first-exposure confusion, and make the responses in the main trials more stable.

After the practice phase, participants completed the main trial block. The protocol noted that participants needed to say aloud what they thought was happening or where they thought the hazard was coming from, in order to support interpretation of the responses.

Once the trials were finished, participants completed the NASA-TLX (Appendix K) and the post-test Van der Laan scale.

Finally, a short semi-structured interview was conducted (Appendix M). The interview focused on the following **main questions**:

1. which warnings were easiest or most difficult to understand;
2. whether the helmet or handles felt more directionally clear;
3. whether either prototype influenced braking;
4. whether the warnings felt helpful, stressful, or irritating;
5. whether the system increased the sense of safety or control;
6. whether participants would want to use such a system in daily cycling;
7. what they liked or disliked about the prototypes;
8. what they would improve;
9. and how they experienced the test overall.

Depending on the participant, the full session took approximately 45 to 60 minutes. This was mainly related to differences in the time needed for explanation, calibration, questionnaire completion, and qualitative feedback.

10.8 MEASURES

The study combined questionnaire data, observational data (Appendix L), and supportive behavioural measures. These measures were selected to reflect the study's main aim: evaluating acceptability, clarity, perceived safety, and interaction quality.

Mental workload

Mental workload was assessed using the NASA Task Load Index (NASA-TLX), a multidimensional subjective workload measure consisting of six subscales: Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration (Hart & Staveland, 1988). The paper form used in the study explicitly listed these six dimensions and their guiding questions.

Acceptance and user experience

Acceptance was assessed using the Van der Laan acceptance scale, which measures two main dimensions: usefulness and satisfaction (van der Laan et al., 1997). The scale was administered before and after use in order to compare expected acceptance with experienced acceptance. The version used in the study presented the standard item pairs associated with usefulness and satisfaction.

Qualitative feedback

Qualitative data were collected through a short semi-structured interview after the trial block. These interview data were used to explore how participants described the clarity, usefulness, safety, irritation, and overall experience of the feedback system. The interview was also important for identifying possible tensions between how a signal was perceived and how it influenced behaviour.

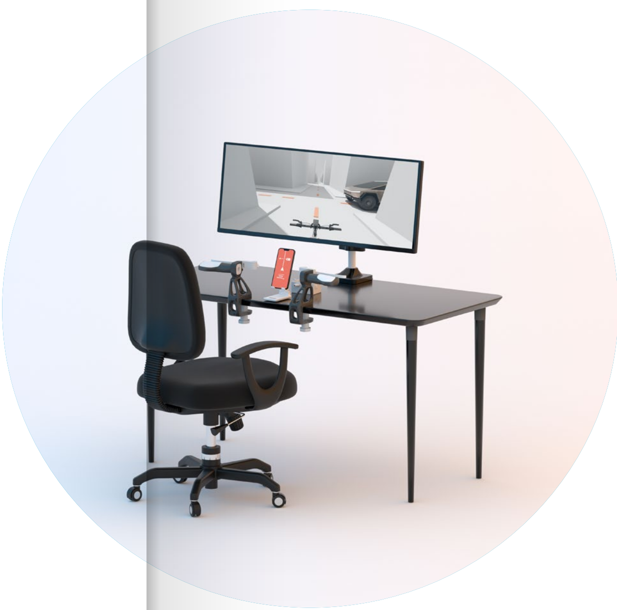
Reaction time behaviour

An important objective measure in the study is the reaction time between the moment the haptic cue is activated and the participant’s first observable behaviour, such as braking input. This measure provides insight into how quickly a warning is noticed and processed.

Braking behaviour

In addition to reaction time, the nature of the reaction was also examined. Because the handles register braking input, it is possible to investigate whether participants respond with a left, right or combined braking action. This is relevant because directional haptics may not only direct attention but also unintentionally influence motor behaviour.

These last two behavioural measures were treated as supportive rather than as the primary focus of the study. The trial observation sheet additionally recorded, for each trial, whether the situation was interpreted correctly, whether the response was missed, and whether visible hesitation or confusion was absent, slight, or clear.



10.9 DATA HANDLING AND PRIVACY

Participants first signed the informed consent form using their name, after which they were assigned a participant ID. From that point onward, the participant ID was used on all research materials. The participants were informed that the consent forms were stored separately from the research data, the questionnaire sheets and test sheets were stored under participant ID only, and that the digital behavioural data such as reaction time and brake input were likewise linked only through participant ID. The informed consent form also stated that participants could request deletion of their identifiable or linkable data until 9 April 2026, after which the remaining dataset could be treated as pseudonymised and non-directly identifiable (Appendix O).

10.10 CONCLUDING REMARKS

In summary, the study used a small-scale within-subject mixed-method design in which participants experienced three feedback conditions across a limited set of representative simulated traffic scenarios. The setup combined a vibrating helmet, vibrating handles, and a seated desktop-based simulation environment. Data collection included the NASA-TLX, the Van der Laan acceptance scale, supportive behavioural logs, researcher observations, and a short post-test interview. Together, these measures were intended to determine whether the directional haptic warning system could be regarded as an acceptable interaction modality in the present simulated cycling context.

USER TESTING **RESULTS**

This chapter presents the findings of the user evaluation of the directional haptic warning system. The results are organised into four main parts. First, perceived workload is reported using the NASA Task Load Index. Second, acceptance is reported using the Van der Laan acceptance scale. Third, the supportive behavioural and observational findings are presented, focusing on interpretation, missed responses, hesitation, and braking behaviour. Fourth, the qualitative findings are summarised in relation to clarity, usefulness, safety, irritation, and overall experience. The chapter concludes with an explicit evaluation of the hypotheses.

11.1 NASA-TLX WORKLOAD

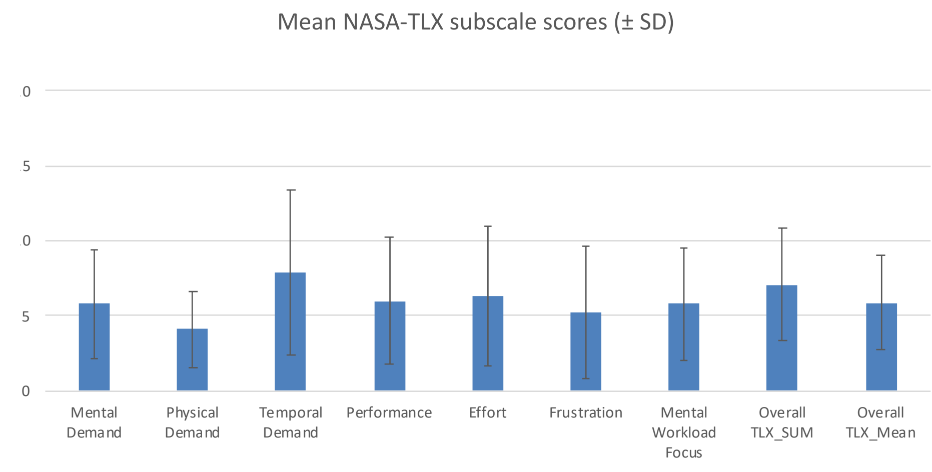
Perceived workload was assessed using the NASA Task Load Index (NASA-TLX), a multidimensional subjective workload instrument consisting of the six subscales Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration (Hart & Staveland, 1988). Because participants completed the paper NASA-TLX by marking positions on the response lines and no pairwise weighting procedure was administered, the questionnaire was analysed here as a raw six-subscale measure. Each subscale was scored on a 1-20 scale, with lower values indicating a more favourable outcome and higher values indicating a higher perceived workload.

Across the 13 participants, the overall raw NASA-TLX (Figure 11.1) mean score was 5.88 (SD = 3.10), indicating that the experienced workload was generally at the lower end of the response scale. When the six standard subscales were considered separately, Temporal Demand showed the highest mean score (M = 7.92, SD = 5.50), followed by Effort (M = 6.31, SD = 4.63), Performance (M = 6.00, SD = 4.26), Mental Demand (M = 5.77, SD = 3.61), Frustration (M = 5.23, SD = 4.42), and Physical Demand (M = 4.08, SD = 2.53). This pattern suggests that the system was not experienced as physically demanding, and that the main workload contribution arose more from the pace of the scenarios and the effort required to interpret and respond to the warnings than from bodily strain.

In addition to the six standard NASA-TLX subscales, an exploratory composite score labelled Mental Workload Focus was calculated (Figure 11.1). This score was defined as the mean of Mental Demand, Effort, and Frustration, resulting in a mean of 5.77 (SD = 3.79). This composite is not part of the original NASA-TLX instrument, but was added here as an interpretive summary of the dimensions most directly related to the present study's hypothesis of acceptable mental workload rather than workload in the broader sense.These three subscales were selected for a specific reason, because they provide the clearest descriptive indication of whether the system imposed an acceptable level of mental burden as such during use. This in contrary to the other 3 subscales.

The Mental Workload Focus score remained on the lower part of the scale and was closely aligned with the overall raw NASA-TLX mean. This indicates that, although some effort and time pressure were present, participants generally did not experience the system as highly mentally taxing, frustrating, or excessively effortful. At the same time, the comparatively higher Temporal Demand score suggests that the workload was not entirely absent. Instead, some participants appear to have experienced the timing or pace of the simulated hazard situations as more demanding than the other workload subscales.

Overall, the NASA-TLX findings suggest that the prototype was generally manageable from a workload perspective. The results do not indicate that the system imposed a strong or excessive cognitive burden, although they do suggest that the pace and timing of the simulations may still require refinement.



NASA-TLX scores

Subscale	Description	Mean	SD
Mental Demand	Reflects the extent to which the task was cognitively demanding	5,77	3,61
Physical Demand	Primarily reflects bodily strain	4,08	2,53
Temporal Demand	Relates more specifically to pace and time pressure	7,92	5,5
Performance	Reflects self-evaluation of task success	6	4,26
Effort	Reflects how hard participants felt they had to work to reach their level of performance	6,31	4,63
Frustration	Reflects the extent to which the interaction was experienced as stressful, irritating, or discouraging	5,23	4,42
Mental Workload Focus	Mean of Mental Demand, Effort and Fustration	5,77	3,79
Overall TLX_SUM		7,06	3,73
Overall TLX_Mean		5,88	3,1

Figure 11.1: shows the mean NASA-TLX subscale scores, including the exploratory Mental Workload Focus composite, with standard deviation error bars.

11.2 VAN DER LAAN ACCEPTANCE SCALE

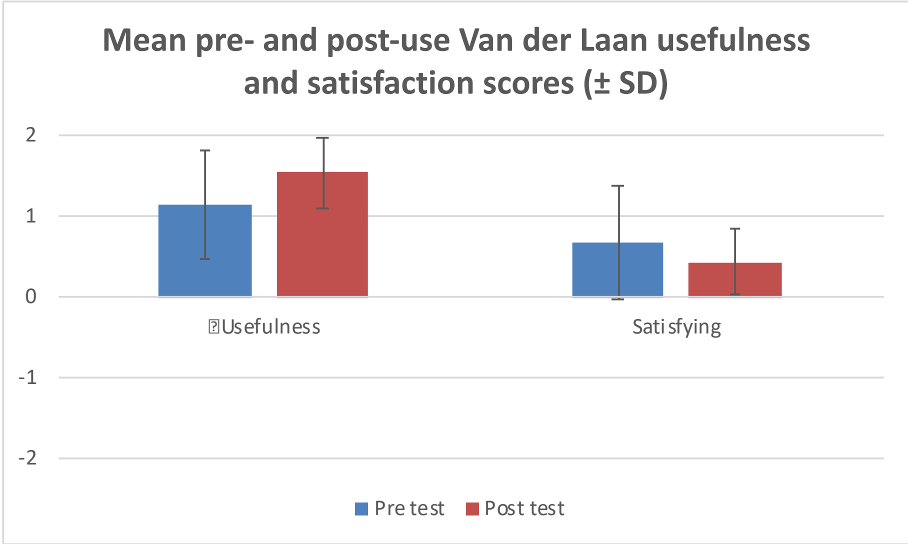
Acceptance was assessed using the Van der Laan acceptance scale, which measures two main dimensions, namely usefulness and satisfaction, and is commonly used to assess acceptance of transport-related systems (van der Laan et al., 1997). The scale was administered both before and after the trial block in order to compare expected acceptance with experienced acceptance. Dimension scores on the Van der Laan scale range from −2 to +2, with more positive values indicating more favourable evaluations and values around zero indicating a more neutral evaluation (Figure 11.2).

The mean usefulness score increased from 1.15 before testing (SD = 0.68) to 1.54 after testing (SD = 0.44). The mean satisfying score remained relatively stable, increasing slightly from 0.63 before testing (SD = 0.71) to 0.67 after testing (SD = 0.41).

These results indicate that participants already held a positive initial expectation of the system and continued to evaluate it positively after experiencing it. The clearest change occurred in the usefulness dimension, suggesting that direct interaction with the prototype strengthened participants' perception of its practical value. By contrast, the satisfying dimension changed only marginally, indicating that affective appreciation of the system remained relatively stable across the two measurement moments.

Internal consistency showed a mixed pattern across dimensions and time points (Figure 11.3). For the pre-test, internal consistency was high for usefulness ($\alpha = 0.82$) and acceptable for satisfaction ($\alpha = 0.71$). For the post-test, internal consistency was lower, with $\alpha = 0.53$ for usefulness and $\alpha = 0.18$ for satisfying. These alpha values indicate that the pre-test dimension scores were more internally consistent than the post-test scores, particularly for the satisfying dimension. The post-test satisfaction result should therefore be interpreted with caution.

Taken together, the Van der Laan results suggest a generally positive acceptance of the prototype on both dimensions. Participants rated the system positively on usefulness and satisfaction both before and after testing, with the strongest positive shift occurring for usefulness. This means that the system was easier to justify as functionally valuable than as fully pleasant or desirable in its current form.



Dimension	Pre test	Post test	Pre SD	Post SD
Usefulness	1,15	1,54	0,68	0,44
Satisfying	0,68	0,44	0,71	0,41

Figure 11.2 presents the mean Van der Laan usefulness and satisfaction scores before and after use, with standard deviation error bars.

Reliability block (Cronbach's alpha)

Participant_ID	Total_Usefulness_Pre	Total_Satisfying_Pre	Total_Usefulness_Post	Total_Satisfying_Post
1	0	0	3	2
2	2	2	7	4
3	3	-1	5	1
4	8	5	9	3
5	1	4	5	5
6	7	3	9	2
7	10	6	10	4
8	8	-1	9	1
9	8	4	8	1
10	10	8	10	6
11	6	2	9	2
12	8	2	9	1
13	4	-1	7	3
Total score variance	11,52564103	8,102564103	4,730769231	2,730769231
Sum item variances	3,961538462	3,794871795	2,717948718	2,371794872
Alpha	0,820355951	0,708860759	0,531842818	0,175273865
Acceptance	High	High	Low	Low

Figure 11.3. Reliability block showing internal consistency (Cronbach's alpha) for the pre-test and post-test Van der Laan usefulness and satisfaction scales.

11.3 BEHAVIOURAL AND OBSERVATIONAL RESULTS

In addition to the questionnaire data, the study also included supportive behavioural and observational measures. These measures focused on four main indicators: correct interpretation, missed response, hesitation, and brake behaviour (Figure 11.4 - 11.5).

At the level of feedback modality, the helmet condition showed the strongest overall results (Figure 11.4). Correct interpretation was highest in this condition at 87.76%, while the percentage of missed responses remained low at 2.00%. The average hesitation score was also lowest in the helmet condition (0.46), indicating relatively little visible doubt or confusion. The handlebar condition performed less strongly, with 68.75% correct interpretation, 2.08% missed responses, and a hesitation score of 0.63. The no-feedback condition showed the least favourable pattern, with 47.06% correct interpretation, 58.82% missed responses, and the highest hesitation score (1.44).

These results indicate that directional haptic feedback helped participants to interpret the traffic situation more effectively than when no feedback was available. Within the two haptic modalities, the helmet appeared to be the clearest and most directly interpretable in this dataset.

At the scenario level, the car on the right was interpreted most successfully, with 91.67% correct interpretation and a low hesitation score of 0.56. The car coming from the left showed 71.05% correct interpretation and a hesitation score of 0.77. The overtake scenario was the most difficult, with 60.00% correct interpretation and a hesitation score of 0.71. Because the overtaking scenario involved only a cyclist approaching from the rear-left, this result should be interpreted as reflecting a specific overtaking configuration rather than overtaking situations in general.

At the level of individual trial combinations (Figure 11.5), Scenario G (RechtsAuto_Helmet) and Scenario B (RechtsAuto_Hand) both reached 100.00% correct interpretation with 0.00% missed responses. Participants were not informed that no overtaking cyclist would appear from the right, so this result cannot be attributed to explicit prior knowledge of the test structure. However, right-sided warnings were effectively less ambiguous within the experiment, as they were only associated with a car approaching from the right at an intersection. Left-sided warnings were more complex, because they could indicate either a car approaching from the left or an overtaking cyclist from the rear-left. Lower performance on left-sided trials is therefore not unexpected, as reflected in Scenario C (87.50% correct interpretation, 6.25% missed responses) and Scenario H (75.00% correct interpretation, 8.33% missed responses). More notable is the contrast within the overtaking condition: Scenario D (Inhalen_Hand) reached only 35.00% correct interpretation and had a hesitation score of 1.00, indicating slight hesitation on a scale where 0.00 represents no hesitation and 2.00 represents clear hesitation. By comparison, Scenario A (Inhalen_Helm) reached 85.00% correct interpretation, 0.00% missed responses, and a lower hesitation score of 0.43. This suggests a clear modality-related difference within the overtaking scenario that cannot be explained by cue ambiguity alone.

Brake behaviour showed a more mixed picture. The percentage of correct brake use was highest in the helmet condition (60.00%), followed by the no-feedback condition (50.00%) and the handlebar condition (45.83%). At the scenario level, overtaking showed the highest correct brake use (58.54%), followed by a car coming from the left (51.28%) and a car coming from the right (47.22%).

The distribution of the first brake action also revealed a notable directional pattern. In the right car scenario, participants first used the right brake in 86.11% of cases, whereas in the left car scenario, they first used the left brake in 76.92% of cases. In the Overtake scenario, the pattern was more spread, with 21.95% not braking, 53.66% first using the left brake, and 24.39% first using the right brake.

Taken together, these data suggest that participants often translated directional hazard information into directional braking behaviour. Although this may reflect a natural response tendency, it also identifies a critical design concern: a directional warning should not encourage a cyclist to brake only on the same side as the warning. This issue became especially important when interpreted together with the interview findings.

Trial scores per feedback modality & Scenario type

	N	Correct interpretation (higher % is better)	Missed response (lower % is better)	Hesitation	No brake (%)	Left brake first (%)	Right brake first (%)	Correct brake use (%)
Helmet	50	87,76%	2,00%	0,46				60,00%
Handles	48	68,75%	2,08%	0,63				45,83%
No feedback	18	47,06%	58,82%	1,44				50,00%
Overtake	41	60,00%	0,00%	0,71	21,95%	53,66%	24,39%	58,54%
Car right	36	91,67%	11,11%	0,56	5,56%	8,33%	86,11%	47,22%
Car left	39	71,05%	21,05%	0,77	7,69%	76,92%	15,38%	51,28%

Figure 11.4 presents the trial scores per feedback modality, and per scenario type

Trial scores per scenario

Scenario	description	N	Correct interpretation (higher % is better)	Missed response (lower % is better)	Hesitation	No brake (%)	Left brake first (%)	Right brake first (%)	Correct brake use (%)
A	(Inhalen_Helm)	21	85,00%	0,00%	0,43	28,57%	38,10%	33,33%	71,43%
B	(RechtsAuto_Hand)	12	100,00%	0,00%	0,42	8,33%	0,00%	91,67%	41,67%
C	(LinksAuto_Hand)	16	87,50%	6,25%	0,31	0,00%	87,50%	12,50%	50,00%
D	(Inhalen_Hand)	20	35,00%	0,00%	1,00	15,00%	70,00%	15,00%	45,00%
E	(LinksAuto_NoFeedback)	11	40,00%	60,00%	1,45	27,27%	54,55%	18,18%	45,45%
F	(RechtsAuto_Nofeedback)	7	57,14%	57,14%	1,43	0,00%	14,29%	85,71%	57,14%
G	(RechtsAuto_Helmet)	17	100,00%	0,00%	0,29	5,88%	11,76%	82,35%	47,06%
H	(LinksAuto_Helmet)	12	75,00%	8,33%	0,75	0,00%	83,33%	16,67%	58,33%

Figure 11.5 presents the trial scores per scenario

11.4 QUALITATIVE FINDINGS

The qualitative findings showed that participants generally experienced the system as useful, clear, and potentially supportive for safety, but also revealed a critical concern regarding the influence of directional signals on braking behaviour.

The main recurring themes in the qualitative data were:

Helmet feedback was experienced as more directionally clear than handlebar feedback.
Most participants reported that the helmet communicated hazard direction more clearly than the handlebars, including participants who normally do not wear a bicycle helmet.

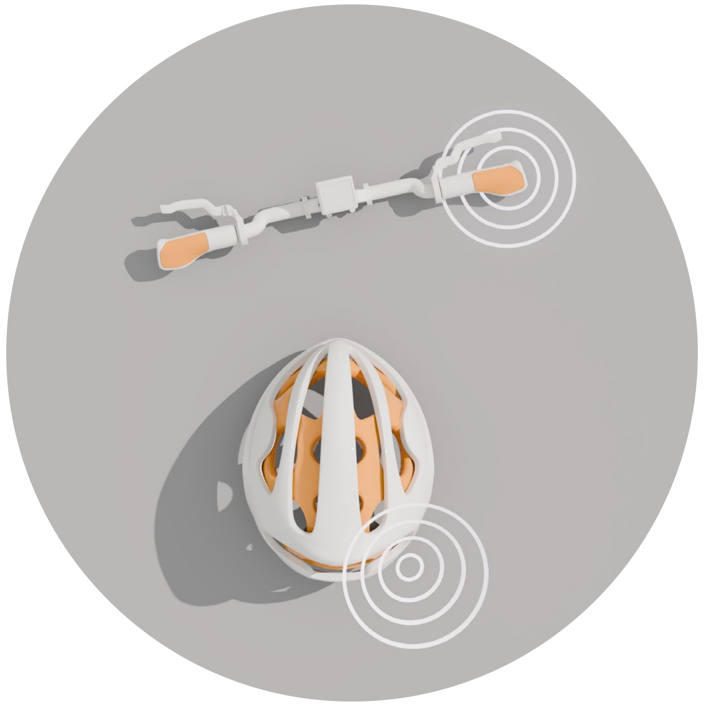
Directional clarity did not automatically lead to preference for daily use.
Although the helmet was often considered clearer, several participants still found the handlebars more attractive in practice because this does not require an additional wearable.

The system was generally experienced as helpful and potentially supportive for safety.
Many participants described the warnings as useful, reassuring, and supportive because they informed them earlier that something was approaching.

Directional vibration sometimes appeared to influence braking behaviour in an undesirable way.
Several participants seemed to brake on the same side as the warning, suggesting that the feedback may sometimes have guided braking behaviour in a way that would not necessarily be desirable in real cycling.

The handlebars were seen as practical but less robust in interpretability.
Participants appreciated that the handlebar feedback did not require wearing a helmet, but it was also more often described as less distinctive or harder to interpret.

The warnings were generally not experienced as highly disturbing, although the helmet was sometimes perceived as intense.
This suggests that the system showed clear value, but that the user experience was not yet uniformly comfortable.



11.5 EVALUATION OF THE HYPOTHESES

The findings show that the directional haptic warning system was evaluated positively on several key dimensions, though with important reservations. Across the quantitative and qualitative data, the system was generally experienced as useful, reasonably understandable, and not excessively demanding. At the same time, the results also revealed a critical tension between directional clarity and safe behavioural interpretation, particularly regarding braking behaviour.

11.5.1 - H1 (Mental Workload)

H1 stated that directional haptic feedback via vibrating handles and a vibrating helmet would be experienced as involving an acceptable level of mental workload. The results provide general support for this hypothesis. The overall raw NASA-TLX mean score was 5.88 (SD = 3.10), indicating that workload remained on the lower part of the response scale. In addition, the exploratory Mental Workload Focus composite, calculated as the mean of Mental Demand, Effort, and Frustration, was 5.77 (SD = 3.79). This suggests that the dimensions most directly related to mental burden remained relatively low overall.

The decision to examine this additional composite was theoretically motivated. Although the NASA-TLX is a multidimensional workload instrument, the present hypothesis concerned mental workload specifically. For that reason, Mental Demand, Effort, and Frustration were considered the most relevant dimensions for a focused interpretation of H1, as they represent cognitive demand, perceived exertion, and negative affective strain during task performance (Hart & Staveland, 1988).

At the same time, the relatively higher Temporal Demand score (M = 7.92, SD = 5.50) indicates that some participants found the pace of the scenarios somewhat demanding.

H1 is therefore supported, although with the qualification that the workload was not equally low for all participants.

11.5.2 - H2 (Usefulness)

H2 stated that the directional haptic feedback would be evaluated positively in terms of perceived usefulness. The data provide clear support for this hypothesis. On the Van der Laan scale, the mean usefulness score increased from 1.15 (SD = 0.68) before testing to 1.54 (SD = 0.44) after testing, indicating that participants evaluated the system as useful overall and even more positively after direct experience with the prototype (van der Laan et al., 1997).

This positive evaluation is reinforced by the qualitative findings. Many participants described the warnings as helpful, useful, or supportive because they informed them earlier that something was approaching. The behavioural and observational data support this interpretation as well. Compared with the no-feedback condition, both haptic conditions showed improved interpretation of the traffic situation, and the helmet in particular produced substantially higher correct interpretation scores. In this sense, the interview data, observation scores, and acceptance ratings all point in the same direction: participants generally recognised the practical value of the haptic warnings.

H2 is therefore clearly supported.

11.5.3 - H3 (Satisfaction)

H3 stated that the directional haptic feedback would be evaluated positively in terms of perceived satisfaction. The results offer partial support for this hypothesis. On the Van der Laan scale, the mean satisfying score remained positive but changed only slightly, from 0.63 (SD = 0.71) before testing to 0.67 (SD = 0.41) after testing. This indicates that the system was not evaluated negatively, but that experienced satisfaction did not increase strongly after use.

The qualitative findings help explain this more modest pattern. Participants clearly saw potential in the concept and often recognised its usefulness, but they also mentioned practical drawbacks and points for improvement, particularly regarding intensity, comfort, and signal interpretation. In addition, the internal consistency of the post-test satisfaction scale was low, meaning that this specific result should be interpreted cautiously.

H3 is therefore only partially supported. Overall, the evidence suggests that participants viewed the system as promising and acceptable, but not yet as unequivocally pleasant or desirable in its current form.

11.5.4 - H4 (Clarity and interpretability)

H4 stated that participants would generally experience the directional haptic feedback as clear and understandable. The results support this hypothesis, although the degree of support differed strongly between the two modalities and also depended partly on the structure of the tested scenarios. The qualitative findings showed that most participants experienced the helmet as more directionally clear than the handlebars. This was also visible in the observational data, where the helmet condition showed the highest correct interpretation (87.76%), the lowest missed response rate (2.00%), and the lowest hesitation score (0.46). By contrast, the handles performed less strongly, with 68.75% correct interpretation and a hesitation score of 0.63, while the no-feedback condition performed worst overall.

Interpretability was not determined by modality alone. Within the experiment, right-sided warnings were effectively less ambiguous because they were only associated with a car approaching from the right at an intersection, even though participants were not explicitly informed of this. Left-sided warnings were more complex, as they could indicate either a car approaching from the left or an overtaking cyclist from the rear-left. This means that some variation in interpretation performance is likely to reflect not only modality effects but also differences in scenario ambiguity.

At the same time, the contrast within the overtaking condition points to a clear modality-related difference. In the overtaking scenario, Scenario A (Inhalen_Helm) reached 85.00% correct interpretation with 0.00% missed responses, whereas Scenario D (Inhalen_Hand) reached only 35.00% correct interpretation and a hesitation score of 1.00. Because both scenarios referred to the same hazard type, this difference cannot be explained by cue ambiguity alone.

H4 is therefore supported, mainly because of the helmet's strong performance rather than because both modalities performed equally well.

11.5.5 - H5 (Safety and irritation)

H5 stated that participants would generally experience the system as supportive for perceived safety and low in irritation. The findings provide mixed support for this hypothesis. On the positive side, many participants reported that the warnings made them feel more alert and better informed about potential hazards, which suggests that the system did contribute to perceived support and safety. In addition, irritation did not emerge as a dominant negative theme in the interviews, although some participants described the helmet as relatively intense. The NASA-TLX frustration score also remained moderately low rather than high (M = 5.23, SD = 4.42), which is consistent with the view that the system was not strongly irritating overall.

However, the behavioural and observational findings introduce an important qualification. Several participants appeared to translate the direction of the warning into the side on which they should brake. This was particularly concerning in the handlebar condition, where unilateral braking on the same side as the hazard occurred relatively often. This means that, although the system could increase alertness and may have supported perceived safety, the current signal design also risked being interpreted in a way that could encourage undesirable braking responses.

H5 cannot be considered fully supported, because of this respons behaviour. The system appears promising in terms of perceived support and generally low irritation, but the present signal design does not yet fully support safe behavioural guidance. H5 is therefore only partially support

11.6 Overall conclusion

Overall, the findings suggest that the main hypothesis is largely supported, though with important qualifications. The directional haptic warning system was generally perceived as acceptable in terms of workload, usefulness, and clarity, with the helmet as the strongest modality for directional interpretation. At the same time, the findings indicate that interpretability depended not only on modality, but also partly on the ambiguity of the scenario-direction mapping within the experimental setup. Satisfaction was positive but modest, and the results related to safety were more ambiguous because the directional nature of the warnings sometimes appeared to influence braking behaviour in an undesirable way.

In summary, H1, H2, and H4 were supported, whereas H3 and H5 were only partially supported. The system therefore demonstrates clear potential as an acceptable and meaningful haptic warning modality, but the current design still requires refinement before it can be considered fully satisfactory and behaviourally robust in a cycling safety context.

PROJECT **DISCUSSION**

This chapter discusses the findings of the user evaluation in relation to the project aim and the broader design question of whether directional haptic feedback can function as an acceptable warning modality in a cycling-related context.

Overall, the findings indicate that directional haptic feedback has clear potential as a warning modality in a cycling-related context. Across the quantitative and qualitative data, the system was generally experienced as useful, reasonably understandable, and not excessively demanding. In this sense, the concept appears promising as a non-visual and non-auditory interface for communicating hazard-related information. This is also in line with the broader project ambition to move from Proof of Technology toward Proof of Value, in which the central question is not only whether the system can function technically, but whether it creates meaningful user value.

At the same time, the findings show that perceptual clarity alone is not sufficient to judge the quality of the system. The helmet performed best in terms of directional interpretation, while the handlebars performed less robustly. However, the main issue is not simply that one modality outperformed the other. More meaningful is that the results indicate that a warning can be experienced as clear while still influencing behaviour in a way that may be undesirable in a real cycling context. This distinction between perceptual clarity and behavioural appropriateness is central to the interpretation of the study.

Feasibility (can it be done?)
From a feasibility perspective, the project demonstrates that a directional haptic warning concept can be realised as a functioning research direction. The system successfully combined a helmet module, a handlebar module, head tracking, wireless communication, and a simulated test environment into one coherent platform. At the same time, feasibility remains limited to a controlled setup. The present study does not yet demonstrate feasibility under real cycling conditions, and the prototype still revealed practical issues such as haptic leakage through the handlebar and sensitivity to physical integration choices.

Viability (will it survive on the longer term?)
From a viability perspective, the concept appears promising as a Proof of Value trajectory. It addresses a meaningful problem, namely the mismatch between the growing availability of digital traffic information and the lack of a suitable low cognitive load interface for elderly cyclists in safety-critical situations. However, the concept cannot yet be considered viable as a deployable safety solution. The current implementation still depends on simulated event logic rather than live V2X infrastructure, and the behavioural findings show that the current signal language is not yet robust enough for safe real-world use.

In addition, the longer-term viability of the concept is partly dependent on the further development and wider adoption of V2X systems in traffic. The value of such a warning interface is likely to increase as more vehicles, infrastructure, and road users become digitally connected. However, this also means that implementation is unlikely to occur all at once and will more plausibly take place in a gradual manner. In that respect, a stepwise implementation pathway may be more realistic, in which e-bikes could initially make use of hazard data derived from other sensing technologies, such as camera- or LiDAR-based systems mounted on the bicycle itself. In this way, the haptic interface could already provide practical value before a fully developed V2X environment becomes widely available.

Desirability (does it address the user's value and needs?)
From a desirability perspective, the findings are positive but mixed. The concept was clearly valued in terms of usefulness and its potential as a warning modality, and the helmet was experienced as the clearest modality. However, satisfaction remained more modest, which suggests that the current implementation was seen more as promising than as fully refined, pleasant, or desirable. In addition, several participants appeared to recognise a tension between clarity and adoption: even when the helmet was considered clearer, the handlebars could still be seen as more attractive in daily use because they do not require an additional wearable product. This indicates that perceptual performance and practical acceptance are not identical. The adoption rate could however be improved if helmet use were to become compulsory

The most important critical finding concerns the relationship between warning direction and braking behaviour. Several participants appeared to translate the direction of the vibration into the side on which they should brake. From a design perspective, this is a serious issue. The concept was intended as an early warning system that supports situational awareness and assessment, not as a signal that prescribes a directional response behaviour. The present findings suggest that the current signal language does not yet fully preserve that distinction. This issue appeared especially clearly in the handlebar condition, which may indicate that signals delivered directly to the hands are more likely to prime a motor response than signals delivered around the head.

Several limitations should also be considered. The study used a relatively small convenience sample, a seated desktop-based simulation, and a deliberately limited scenario set. In addition, the overtaking condition covered only one specific rear-left cyclist situation, and the scenario structure made right-sided warnings less ambiguous than left-sided warnings. The findings should therefore be understood as exploratory and indicative rather than definitive.

RECOMMENDATIONS & **CONTINUATION**

This chapter translates the main findings of the user evaluation into recommendations for further development of the directional haptic warning system.

Refine the signal language
The strongest recommendation is to redesign the warning logic so that directional cues are less likely to be interpreted as an instruction for unilateral braking. The warning should remain informative without becoming behaviourally prescriptive.

Differentiate the roles of helmet and handlebars
The helmet appears especially suitable for directional awareness, whereas the handlebars may be better suited to a more general alerting function. Future iterations should therefore explore whether the two modalities should fulfil different roles rather than identical ones.

Improve haptic pattern design
Future work should investigate how vibration localisation, rhythm, timing, duration, and intensity influence both interpretability and behavioural meaning, to preserve clarity while reducing undesirable behaviour.

Expand and rebalance the scenario set
A future study should include a more symmetrical and varied scenario structure, including overtaking from both sides and multiple traffic actors. This would make it easier to separate true modality effects from effects caused by scenario ambiguity.

Increase ecological validity
The current desktop-based simulation was suitable for an initial user-centred evaluation, but future testing should move gradually toward more realistic cycling conditions, for example through richer simulator setups or controlled on-bike testing.

Improve technical robustness
Further development should address practical issues such as vibration leakage through the handlebar, the effect of motor orientation and localisation, and improved stability of head tracking. These factors directly affect interpretability and interaction quality.

Address comfort and adoption more explicitly
The helmet performed best in terms of directional clarity, but this does not automatically guarantee acceptance in daily use. Future development should therefore balance signal performance with comfort, fit, wearability, and realistic user adoption.

PROJECT **EVALUATION**

This evaluation of my master's thesis marks the final chapter, and with it, my studies at TU Delft comes to an end.

Looking back on the overall graduation project, I can say that the initial phase was quite difficult and time-consuming. It took a considerable amount of time before I found a suitable graduation assignment. This process was often frustrating, with several disappointments and limited progress. This was partly because many of the available projects did not feel ambitious enough, and partly because other options did not align well with my interests and goals. In the end, I decided to initiate my own project idea.

Finding suitable supervisors also proved challenging at first, but this was eventually resolved.
Starting the project itself was not straightforward, as the idea I had in mind was difficult to develop independently without professional expertise in the field of mobility. For that reason, I was very pleased to be able to carry out the project under the supervision of the organisation MODYN. Once the project had been properly initiated, the process progressed more smoothly.

I experienced the collaboration with MODYN and my supervisors as very positive. The contact with Gazelle was also particularly valuable. Many people were willing to contribute, think along, or make time for the project. Throughout the process, I clearly felt that there was enthusiasm for the project and belief in its relevance, which was very motivating.

To structure and monitor the project, I wrote a weekly reflective letter to myself. This worked very well to document the progress of the process, and at the same time, it kept my supervisors informed. It really helped me to reflect on decisions, organise my thoughts, and maintain a clearer overview throughout the project. This was one of the learning goals I had set for myself at the start of the project.

Because I was really determined to go through all stages of the design process, the project became somewhat too extensive for the available timeframe. The total process appeared to be very demanding in terms of time. In particularly developing the prototype required a significant amount of effort. The user testing also took more time than I had initially expected, and writing the final report proved to be a considerable challenge.

At the same time, I occasionally found the formal requirements and procedures of the TU Delft graduation process challenging. These often required a considerable amount of time and effort, while the project itself already demanded a great deal of attention. Although I understand the importance of such requirements in ensuring quality and structure, they sometimes felt restrictive and not always well aligned with the practical pace of the project.

Overall, this project has helped me to grow as a designer and as a person.

PERSONAL **REFLECTION**

This graduation project was very intensive. The process has been an enjoyable and highly valuable learning experience. In addition, the process was at times stressful, demanding, and overwhelming, but ultimately it confirmed the type of designer I aspire to become.

As outlined in the design brief (Appendix E), the project was intended to demonstrate my ability to manage the full design process, including ideation, prototyping, testing, iteration, documentation, and substantiation. In retrospect, I believe I achieved this, even though the project became broad and at times overly ambitious. Nevertheless, it brought together many of the qualities that align with my strengths as a designer, particularly the combination of design, technology, interaction, and hands-on making.

The project made me more aware of my own tendencies. My ambition and interest in exploring multiple directions at once generated energy and led to many ideas, but it also made it more difficult to maintain focus and contributed to a considerable amount of self-imposed stress. I placed high expectations on the quality, technical credibility, and academic substantiation of the work, which often resulted in long working hours and mental pressure.

In addition, the project enabled clear growth in areas that I usually find more challenging. I improved in expressing design decisions in writing, structuring my process, and reflecting more consistently on my work. Tools such as weekly updates, the logbook and project management in Notion supported this development.

Furthermore, the guidance from my supervisors and the professional context at MODYN were highly valuable, as they helped me keep the project realistic and gave insight into the dynamics of a design studio environment. Although the individual nature of the project sometimes felt isolating, it also highlighted the importance of collaboration for me.

I look back on the project with a positive feeling, and I feel not only proud of the result, but also of the personal and professional growth I achieved throughout the graduation project.

REPORT **REFERENCES**

Adafruit Industries. (n.d.). Adafruit DRV2605L haptic motor controller – STEMMA QT / Qwiic (Product ID 2305). Adafruit. https://www.adafruit.com/product/2305

Al-Taie, A., Wilson, G., Goodge, T., Pollick, F., & Brewster, S. (2024). Bike to the Future: Designing Holistic Autonomous Vehicle-Cyclist Interfaces. 194. https://doi.org/10.1145/3640792.3675727

Bosch Mobility. (n.d.). https://www.bosch-mobility.com/en/solutions/sensors/interior-monitoring-systems/

Centraal Bureau voor de Statistiek. (2024). Hoeveel mensen komen om in het verkeer? Centraal Bureau Voor De Statistiek. https://www.cbs.nl/nl-nl/visualisaties/verkeer-en-vervoer/verkeer/hoeveel-mensen-komen-om-in-het-verkeer-

Chocksey, J. S. (2023, January 26). WHAT IS THE POLESTAR SMART EYE DRIVER MONITORING SYSTEM? Jdpower. https://www.jdpower.com/cars/shopping-guides/what-is-the-polestar-smart-eye-driver-monitoring-system

Coalition for Cyclist Safety [C4CS]. (2025, June 22). How it Works - Coalition for Cyclist Safety. Coalition for Cyclist Safety. https://www.coalitionforcyclistsafety.org/how-we-work/

Espressif Systems. (n.d.). ESP-NOW. ESP-IDF Programming Guide. Geraadpleegd op 11 november 2025, van https://docs.espressif.com/projects/esp-idf/en/stable/esp32/api-reference/network/esp_now.html

European Transport Safety Council [ETSC], Adminaité-Fodor, D., & Jost, G. (2020). HOW SAFE IS WALKING AND CYCLING IN EUROPE? (PIN Flash Report 38). European Transport Safety Council.

Gong, Z. (2024). Challenges and Opportunities of Automotive HMI. In Lecture notes in computer science (p. 23). Springer Science+Business Media. https://doi.org/10.1007/978-3-031-76824-8_3

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In P. A. Hancock & N. Meshkati (Eds.), Human mental workload (pp. 139–183). North-Holland.

Hekkert, P., & Van, M. D. (n.d.). VIP Vision in Design: A Guidebook for Innovators. BIS Publishers.

Huang, Y.-Y., & Li, C.-Y. (2020). Anti-annoying Warning System based on User-centric Design for Cellular V2P Safety.

Jansen, A. J., Dekker, M. C., & Steen, D. van der. (2018). The Vibe of Skating; Design and Testing of a Vibro-Tactile Feedback System. 296. https://doi.org/10.3390/proceedings2060296

Koninklijke Gazelle [Gazelle], & Pelgrim, M. (2025). Product innovation in cycling safety [Slide show].

Lich, T. & Robert Bosch [Bosch]. (2025). Accident Research - How to evaluate new bicycle safety technologies? [Slide show]. Coalition Partner Event, Amsterdam, Netherlands.

Modyn. (2026, March 26). Meet our design professionals: Transforming Ideas into Reality. Modyn. https://www.modyn.com/team-product-design-experts/

Ministerie van Economische Zaken en Klimaat. (2023, December 22). Eén oplader voor nieuwe apparaten vanaf december 2024. Nieuwsbericht | Rijksoverheid.nl. https://www.rijksoverheid.nl/actueel/nieuws/2023/12/22/een-oplader-voor-nieuwe-apparaten-vanaf-december-2024

Nukarinen, T., Rantala, J., Farooq, A., & Raisamo, R. (2015). Delivering directional haptic cues through eyeglasses and a seat. 345. https://doi.org/10.1109/whc.2015.7177736

Olaverri-Monreal, C., & Jizba, T. (2016). Human Factors in the Design of Human–Machine Interaction: An Overview Emphasizing V2X Communication. IEEE Transactions on Intelligent Vehicles, 1(4), 302. https://doi.org/10.1109/tiv.2017.2695891

Raddaoui, O. (2023). Rethinking V2X: Embracing User-First Development for Industry Advancement. SAE Technical Papers on CD-ROM/SAE Technical Paper Series, 1. https://doi.org/10.4271/2023-01-1907

Ryu, G., Lee, Y. J., Kim, Y., & Ji, Y. G. (2024). Evaluating the user experience of V2X Communication Alerts for emergencies in Level 3 Autonomous driving. International Journal of Human-Computer Interaction, 41(11), 6866–6878. https://doi.org/10.1080/10447318.2024.2385193

Silla, A., Ledén, L., Rämä, P., Scholliers, J., Noort, M. van, & Bell, D. (2016). Can cyclist safety be improved with intelligent transport systems? Accident Analysis & Prevention, 105, 134. https://doi.org/10.1016/j.aap.2016.05.003

Straughn, S. M., Gray, R., & Tan, H. Z. (2009). To Go or Not to Go: Stimulus-Response Compatibility for Tactile and Auditory Pedestrian Collision Warnings. IEEE Transactions on Haptics, 2(2), 111. https://doi.org/10.1109/toh.2009.15

SWOV – Instituut voor Wetenschappelijk Onderzoek Verkeersveiligheid. (2022). SWOV-Factsheet Elektrische fietsen en speed-pedelecs. In SWOV-factsheet (pp. 1–20).

SWOV – Instituut voor Wetenschappelijk Onderzoek Verkeersveiligheid. (2022). Factsheet elektrische fietsen en speed-pedelecs. In SWOV-factsheet.

SWOV – Instituut voor Wetenschappelijk Onderzoek Verkeersveiligheid. (2023). SWOV-factsheet fietsers. In SWOV-factsheet.

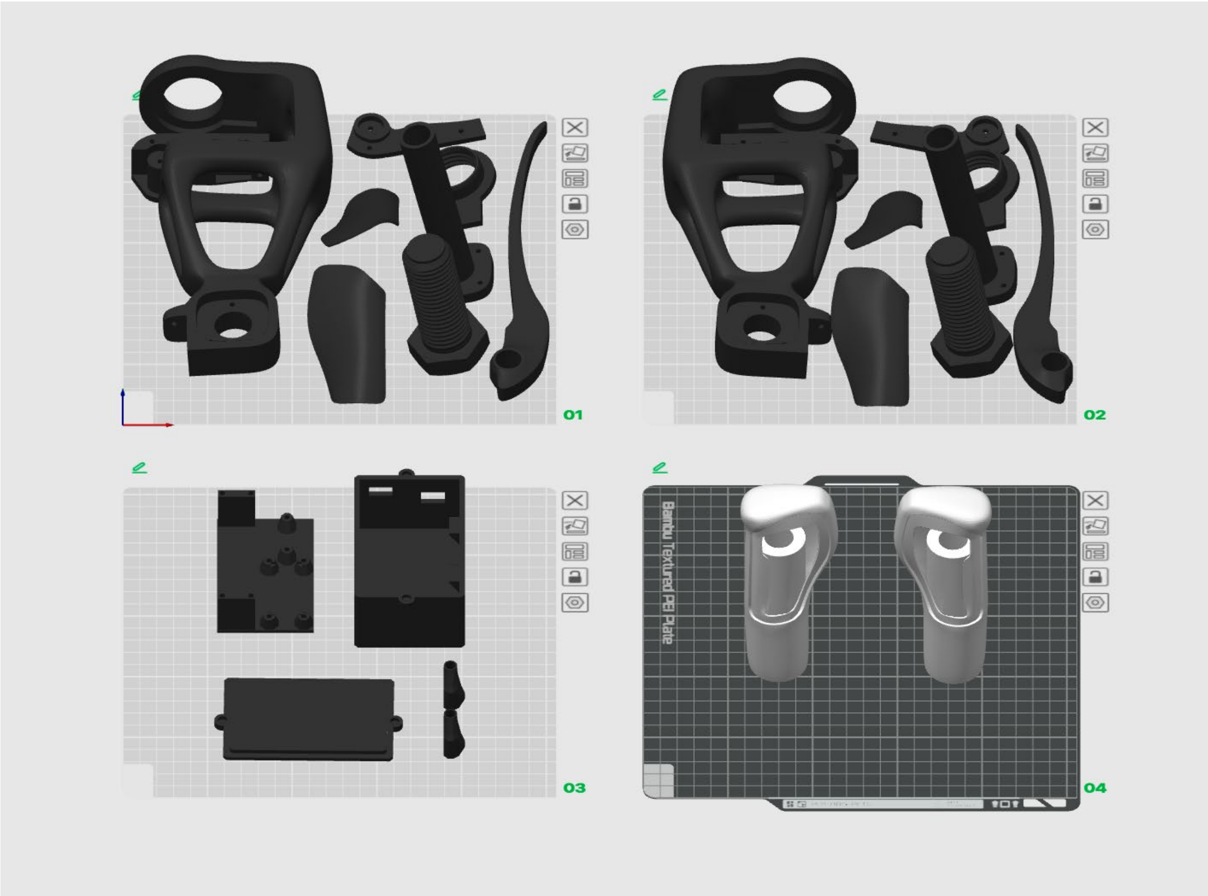
SWOV – Instituut voor Wetenschappelijk Onderzoek Verkeersveiligheid. (2024). SWOV-factsheet ouderen in het verkeer. In SWOV-factsheet.

Tamir, C. (2025). Introduction to V2X. In Coalition For Cyclist Safety, Autotalks Confidential.

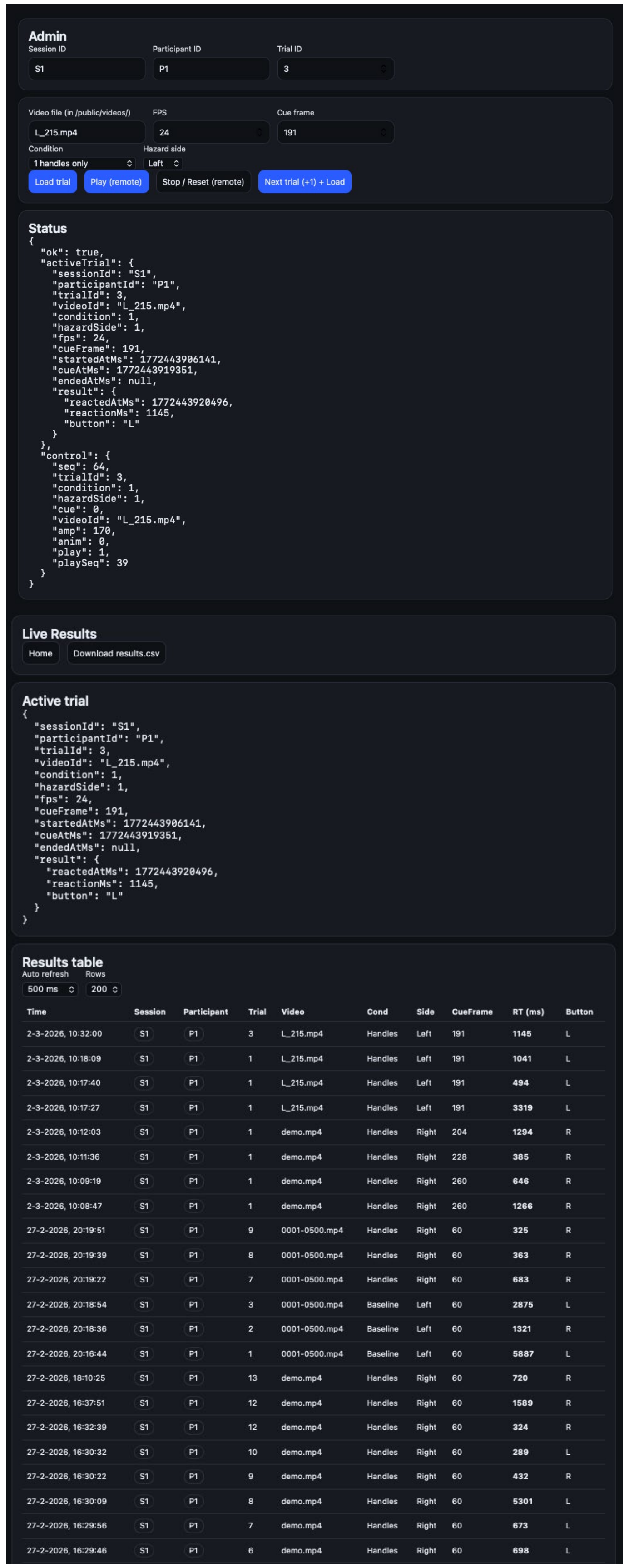
Van der Laan, J.D., Heino, A., & De Waard, D. (1997). A simple procedure for the assessment of acceptance of advanced transport telematics. Transportation Research - Part C: Emerging Technologies, 5, 1-10.

REPORT **APPENDIX**

APPENDIX A - 3D PRINTING ITERERATIONS



APPENDIX B - WEBSERVER (ADMIN & RESULTS PAGE)



Admin

Session ID: S1
Participant ID: P1
Trial ID: 3

Video file (in /public/videos/): L_215.mp4
FPS: 24
Cue frame: 191
Condition: 1 handles only
Hazard side: Left

Load trial | Play (remote) | Stop / Reset (remote) | Next trial (+1) + Load

Status


```
{
  "ok": true,
  "activeTrial": {
    "sessionId": "S1",
    "participantId": "P1",
    "trialId": 3,
    "videoId": "L_215.mp4",
    "condition": 1,
    "hazardSide": 1,
    "fps": 24,
    "cueFrame": 191,
    "startedAtMs": 1772443906141,
    "cueAtMs": 1772443919351,
    "endedAtMs": null,
    "result": {
      "reactedAtMs": 1772443920496,
      "reactionMs": 1145,
      "button": "L"
    }
  },
  "control": {
    "seq": 64,
    "trialId": 3,
    "condition": 1,
    "hazardSide": 1,
    "cue": 0,
    "videoId": "L_215.mp4",
    "amp": 170,
    "anim": 0,
    "play": 1,
    "playSeq": 39
  }
}
```


Live Results

Home | Download results.csv

Active trial

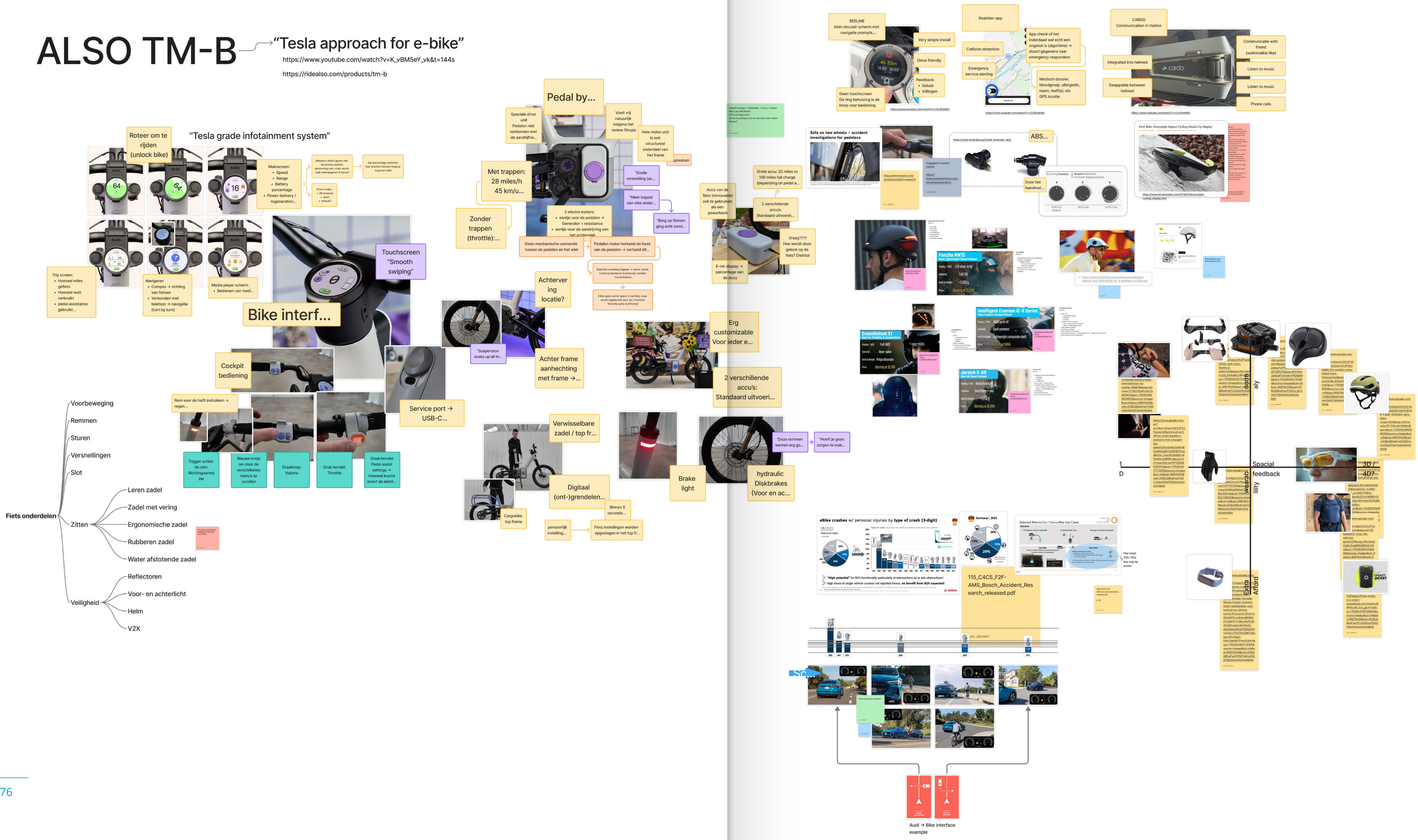

```
{
  "sessionId": "S1",
  "participantId": "P1",
  "trialId": 3,
  "videoId": "L_215.mp4",
  "condition": 1,
  "hazardSide": 1,
  "fps": 24,
  "cueFrame": 191,
  "startedAtMs": 1772443906141,
  "cueAtMs": 1772443919351,
  "endedAtMs": null,
  "result": {
    "reactedAtMs": 1772443920496,
    "reactionMs": 1145,
    "button": "L"
  }
}
```


Results table

Auto refresh: 500 ms
Rows: 200

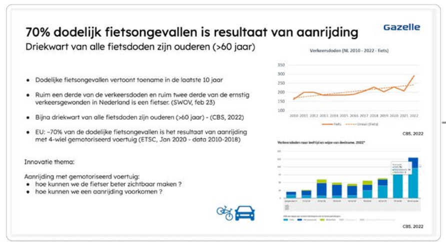
Time	Session	Participant	Trial	Video	Cond	Side	CueFrame	RT (ms)	Button
2-3-2026, 10:32:00	S1	P1	3	L_215.mp4	Handles	Left	191	1145	L
2-3-2026, 10:18:09	S1	P1	1	L_215.mp4	Handles	Left	191	1041	L
2-3-2026, 10:17:40	S1	P1	1	L_215.mp4	Handles	Left	191	494	L
2-3-2026, 10:17:27	S1	P1	1	L_215.mp4	Handles	Left	191	3319	L
2-3-2026, 10:12:03	S1	P1	1	demo.mp4	Handles	Right	204	1294	R
2-3-2026, 10:11:36	S1	P1	1	demo.mp4	Handles	Right	228	385	R
2-3-2026, 10:09:19	S1	P1	1	demo.mp4	Handles	Right	260	646	R
2-3-2026, 10:08:47	S1	P1	1	demo.mp4	Handles	Right	260	1266	R
27-2-2026, 20:19:51	S1	P1	9	0001-0500.mp4	Handles	Right	60	325	R
27-2-2026, 20:19:39	S1	P1	8	0001-0500.mp4	Handles	Right	60	363	R
27-2-2026, 20:19:22	S1	P1	7	0001-0500.mp4	Handles	Right	60	683	R
27-2-2026, 20:18:54	S1	P1	3	0001-0500.mp4	Baseline	Left	60	2875	L
27-2-2026, 20:18:36	S1	P1	2	0001-0500.mp4	Baseline	Left	60	1321	R
27-2-2026, 20:16:44	S1	P1	1	0001-0500.mp4	Baseline	Left	60	5887	L
27-2-2026, 18:10:25	S1	P1	13	demo.mp4	Handles	Right	60	720	R
27-2-2026, 16:37:51	S1	P1	12	demo.mp4	Handles	Right	60	1589	R
27-2-2026, 16:32:39	S1	P1	12	demo.mp4	Handles	Right	60	324	R
27-2-2026, 16:30:32	S1	P1	10	demo.mp4	Handles	Right	60	289	L
27-2-2026, 16:30:22	S1	P1	9	demo.mp4	Handles	Right	60	432	R
27-2-2026, 16:30:09	S1	P1	8	demo.mp4	Handles	Right	60	5301	L
27-2-2026, 16:29:56	S1	P1	7	demo.mp4	Handles	Right	60	673	L
27-2-2026, 16:29:46	S1	P1	6	demo.mp4	Handles	Right	60	698	L

APPENDIX C - SMART E-BIKE EXPLORATION

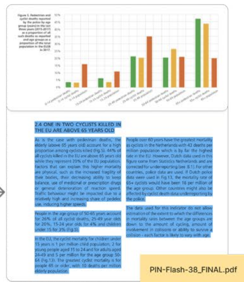


APPENDIX D - RESEARCH EXPLORATION

Leeftijd + ongelukken



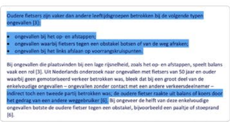
20250604_MP_Product Innovation in cycling safety (NL) (1).pdf



PIN-Flash-38_FINAL.pdf

SWOV (2022). Elektrische fietsen en speed-pedelecs. SWOV-factsheet, mei 2022. SWOV, Den Haag.

FS-Elektrische-fietsen.pdf

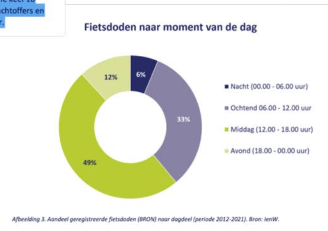


Samenvatting

Ruim een derde van de verkeersdoden en ruim twee derde van de ernstig verkeersgewonden in Nederland is een fietser. Het overlijdensrisico van fietsers (het aantal verkeersdoden per afgelegde afstand) is ruim acht keer zo hoog als dat van automobilisten, maar ruim drie keer zo laag als dat van gemotoriseerde tweewielers. Bijna driekwart van de dodelijke fietsslachtoffers en ruim de helft van de ernstig gewonde fietsers valt onder mensen van 60 jaar en ouder.

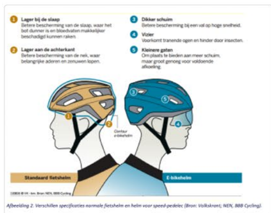
Tabel 2. Het overlijdensrisico naar leeftijdsgroep voor fietsers gebaseerd op het werkelijk aantal verkeersdoden per miljard afgelegde reizigerskilometers (2012-2021). Bron: CBS, bewerking SWOV.

Leeftijd	Risico
0-29 jaar	4
30-49 jaar	5
50-59 jaar	8
60-69 jaar	15
70-79 jaar	46
80+	218
Alle leeftijden	13



Afbeelding 3. Aandeel geregistreerde fietsdoden (BRON) naar dagdeel (periode 2012-2021). Bron: IenW.

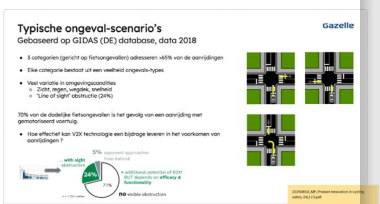
Helm



Brom- en Snorfietser

Soorten ongevallen

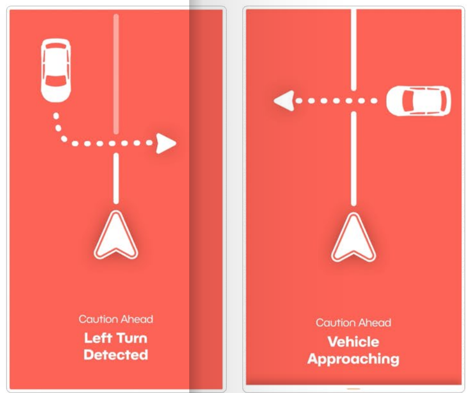
Geen zicht - ongeval



E-bikes

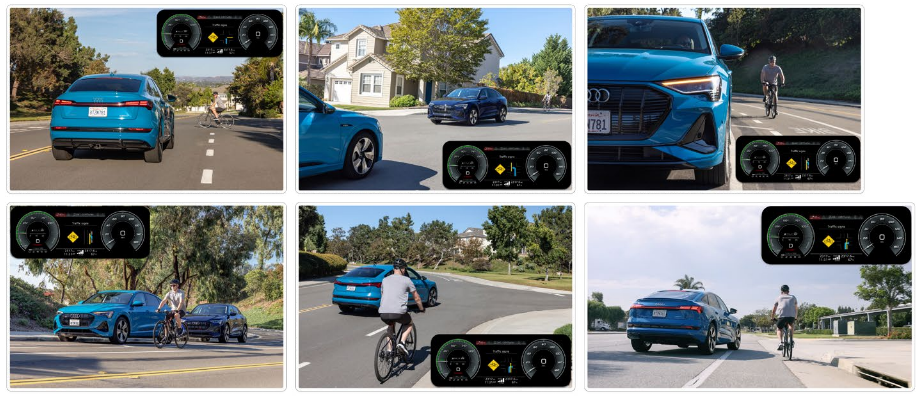
Audi - V2X - Bike

Bicycle interface



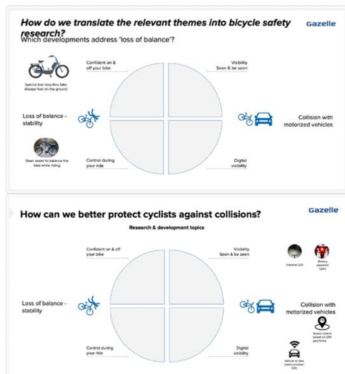
Car interface

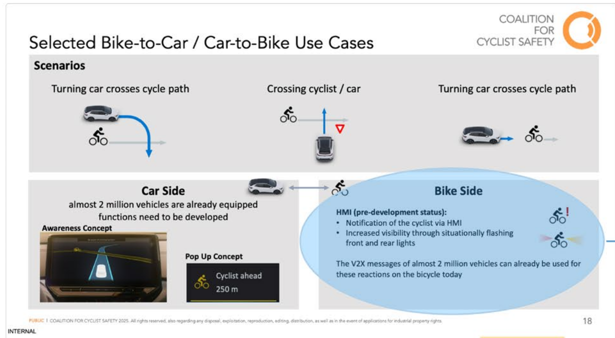
Zie ook nog filmpjes!

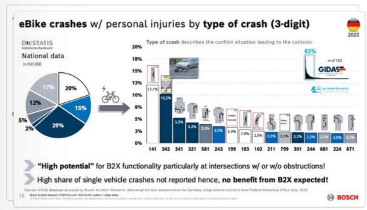


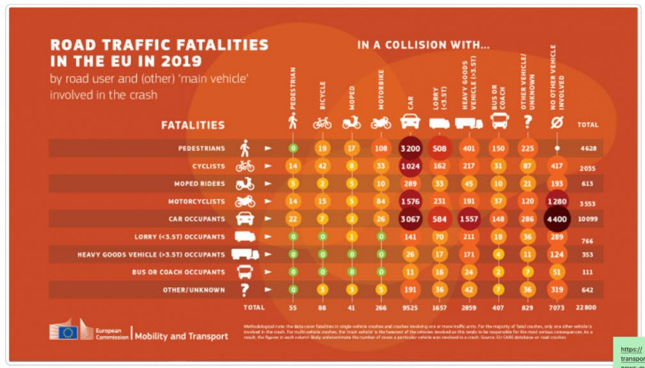
V2X / B2X

Richtingen - verbeteren



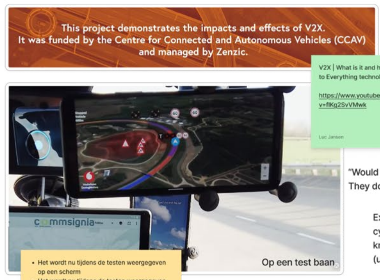






https://transport.ec.europa.eu/news-events/news/road-safety-european-commission-rewards-effective-initiatives-and-publishes-2020-figures-2021-11-18_en

Luc Jansen



V2X | What is it and how does it work | A Vehicle to Everything technology Demo

https://www.youtube.com/watch?v=fIKg2SvVMwk

Luc Jansen

"Would work for cyclist as wel. They don't even need a display"

Example: "Would be nice for cyclist to know a lorry driver knows you are in there blindspot (using V2X)"

- Het wordt nu tijdens de testen weergegeven op een scherm
- Het wordt nu tijdens de testen weergegeven op een scherm (3 jaar geleden)
- Hoe wordt het nu gevisualiseert
- Kan deze feedback niet verbeterd worden
- Echt opkomende systemen

Luc Jansen

Misschien hier VIP op toepassen

→ Ontwerpen voor de toekomst

→ Dit dan naar fietsen toepassen

→ **Hoe feedback naar fietsers**

→ Feedback voor auto's is makkelijker

Luc Jansen

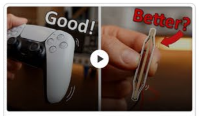
Fietshelmen

Ouderen in het verkeer


Smart&Safe Mobility Lab: Mixed Reality Environment with HIL, CV2X for VRU Detection

Marc González Capdevila, Natanael Vitorino, Yuri Poledna, Bruno Malena, Maikol Funk Drechsler, Gustavo G. Albuquerque, Tales Furlan, Roberto S. Netto

Fig. 1. Mixed Reality Environment concept



I tried Future Technology! (that you can use TODAY)

→ Wordt research paper benoemd!

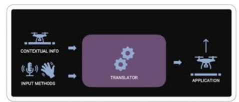
https://www.youtube.com/watch?v=ib9sSugD2WE

Luc Jansen

Vehicle to Everyting

is communicatie tussen voertuigen en hun omgeving.

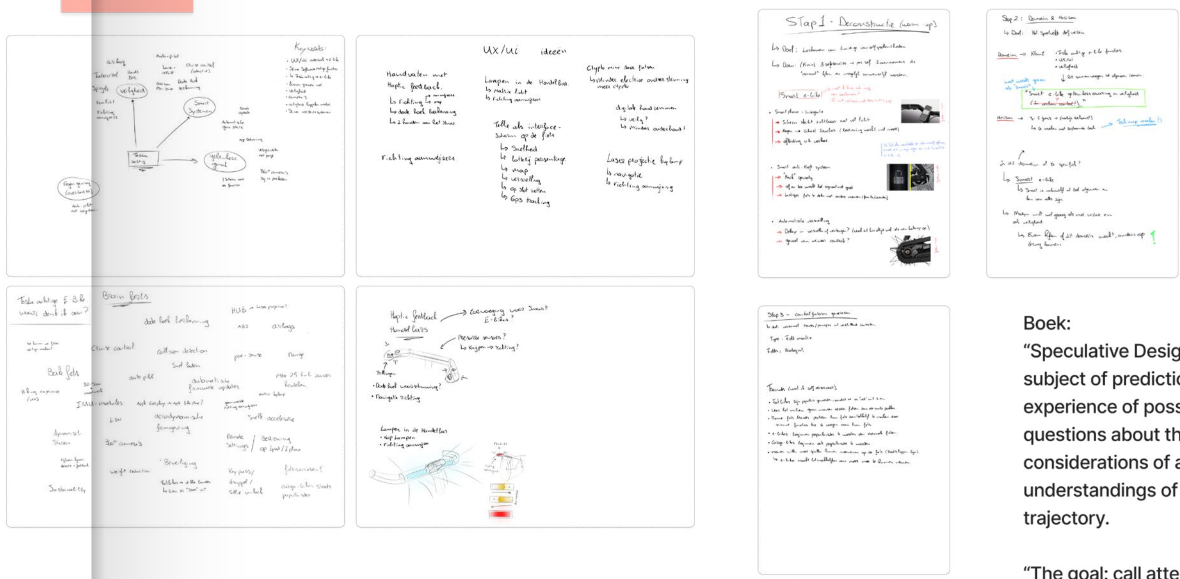
Vehicle to Vehicle	Vehicle to Infrastructure	Vehicle to Pedestrian	Vehicle to Network
Directe datacommunicatie tussen voertuigen via sidelink, zonder tussenkomst van zendmasten. Toepassingen zijn o.a. platooning (auto's die dicht achter elkaar rijden voor efficiëntie), gezamenlijke manoeuvres en het delen van sensorgegevens.	Communicatie tussen voertuigen en infrastructuur zoals verkeerslichten, camera's of sensoren. Dit maakt waarschuwingen voor files of gevaren mogelijk en kan verkeerslichten aanpassen voor noodvoertuigen of openbaar vervoer.	Communicatie tussen voertuigen en apparaten van voetgangers, zoals smartwatches. Dit kan waarschuwingen geven bij oversteekplaatsen of op donkere wegen.	Communicatie via mobiele netwerken met servers. Hiermee kunnen bijvoorbeeld verkeersinformatie, software-updates en noodmeldingen worden uitgewisseld.



What is interaction
- Interaction is *when two or more people or things communicate with or react to each other*
- **Human Machine Interaction** — When we as humans want to interacte with or control any kind of machine
- **History**
  - **Since the potter's wheel, humans have worked with machines using their hands and bodies.**
  - **Early machines were mechanical — simple cause-and-effect interactions (e.g., levers).**
  - **With the microprocessor (1970s) came programmable interfaces, creating a need for intuitive design.**
  - **In the 1980s, the graphical user interface (GUI) introduced the mouse and keyboard, later replaced by touchscreens as the dominant mode of control.**

(335) The Next Paradigm Shift in Human-Machine Interaction | Magnus Arveng | TEDxTrondheim - YouTube

Luc Jansen



Boek:

"Speculative Design (SD) approaches the future not as a subject of prediction, but as a space of critique, offering experience of possible futures as means to provoke questions about the direction society is heading in, considerations of alternative paths, and deeper understandings of the consequences of any given future trajectory.

"The goal: call attention to (or anticipate) future sociotechnical dilemmas and stir debates about the social, political, moral and ethical implications of scientific and technological innovations. "

"SD asks about 'the kinds of futures people really want (Dunne & Raby, 2013, p. 6)"

APPENDIX E - PERSONAL PROJECT BRIEF

DESIGN FOR our future

TUDelft

IDE Master Graduation Project

Project team, procedural checks and Personal Project Brief

In this document the agreements made between student and supervisory team about the student's IDE Master Graduation Project are set out. This document may also include involvement of an external client, however does not cover any legal matters student and client (might) agree upon. Next to that, this document facilitates the required procedural checks:

- Student defines the team, what the student is going to do/deliver and how that will come about
- Chair of the supervisory team signs, to formally approve the project's setup / Project brief
- SSC E&SA (Shared Service Centre, Education & Student Affairs) report on the student's registration and study progress
- IDE's Board of Examiners confirms the proposed supervisory team on their eligibility, and whether the student is allowed to start the Graduation Project

STUDENT DATA & MASTER PROGRAMME
Complete all fields and indicate which master(s) you are in

Family name	Jansen	IDE master(s)	IPD ✔ DfI ☐ SPD ☐
Initials	L.J.	2nd non-IDE master	
Given name	Luc	Individual programme *(date of approval)*	
Student number	4824490	Medisign	☐
		HPM	☐

SUPERVISORY TEAM
Fill in he required information of supervisory team members. If applicable, company mentor is added as 2nd mentor

Chair	Stefan Persaud	dept./section	SDE / DFS
mentor	Joost Alferink	dept./section	HCD / DA
2nd mentor	Gert-Jan van Breugel		
client:	MODYN		
city:	Geldermalsen	country:	Netherlands
optional comments			

! Ensure a heterogeneous team. In case you wish to include team members from the same section, explain why.

! Chair should request the IDE Board of Examiners for approval when a non-IDE mentor is proposed. Include CV and motivation letter.

! 2nd mentor only applies when a client is involved.

APPROVAL OF CHAIR on PROJECT PROPOSAL / PROJECT BRIEF -> to be filled in **by the Chair** of the supervisory team

Sign for approval (Chair)

Name Stefan Persaud Date 21 Oct 2025 Signature

CHECK ON STUDY PROGRESS
To be filled in **by SSC E&SA** (Shared Service Centre, Education & Student Affairs), after approval of the project brief by the chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total ____ EC

Of which, taking conditional requirements into account, can be part of the exam programme ____ EC

✓	YES	all 1st year master courses passed
	NO	missing 1st year courses

Comments:

Sign for approval (SSC E&SA)

Name M.J.H. Neeleman-Smits Date 28-10-2025 Signature

APPROVAL OF BOARD OF EXAMINERS IDE on SUPERVISORY TEAM -> to be checked and filled in by IDE's Board of Examiners

Does the composition of the Supervisory Team comply with regulations?

YES	✓	Supervisory Team approved
NO		Supervisory Team not approved

Comments:

Based on study progress, students is ...

✓	**ALLOWED** to start the graduation project
	NOT allowed to start the graduation project

Comments:

Sign for approval (BoEx)

Name Paul Mommers Date 28-10-2025 Signature

Personal Project Brief – IDE Master Graduation Project

Name student Luc Jansen **Student number**

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT
Complete all fields, keep information clear, specific and concise

Project title Enhancing current (e-)bike Human Machine Interaction using a multimodal feedback system

Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

E-bikes have become animportantpart of urban mobility, with their popularity rising across a wide range of age groups. Elderly riders often depend on e-bikes to remain active yet face physical challenges such as limited mobility and slower reaction times (especially in a busy traffic environments). Teenagers, on the other hand, tend to display less cautious behaviour and are more easily distracted. Additionally, it is increasingly common for cyclists to ride with headphones or noise-cancelling devices, reducing their ability to hear surrounding traffic. These developments raise concerns about awareness and safety on the road.
This project takes place within the domain ofSmart (e-)Bike Human-MachineInteraction (HMI),exploring how biker interactionscan be improved in dense urban settings through more intuitive and non-distracting feedback systems. The main stakeholders includee-bike users,who benefit from enhanced spatial awareness and safety. Other stakeholders arecar drivers and pedestrians, who rely on predictable cyclist behaviour;e-bike manufacturers andmobility tech companies, who seek innovation and safety improvements; andfinally, government and traffic safety institutions, whose goal is to reduce urban traffic accidents.
A big opportunity for this project is the rising popularity of e-bikes, making the market increasingly open to innovation in interaction design and embedded systems, moving from baseline e-bikes towards smart-bikes with all the bells and whistles. However, the context also presentslimitations, including physical constraints on bicycle interfaces, potential resistance to new technology (especially among older users), and technical challenges like power consumption, weight-distance ratio and weatherproofing.

➔ *space available for images / figures on next page*

introduction (continued): space for images

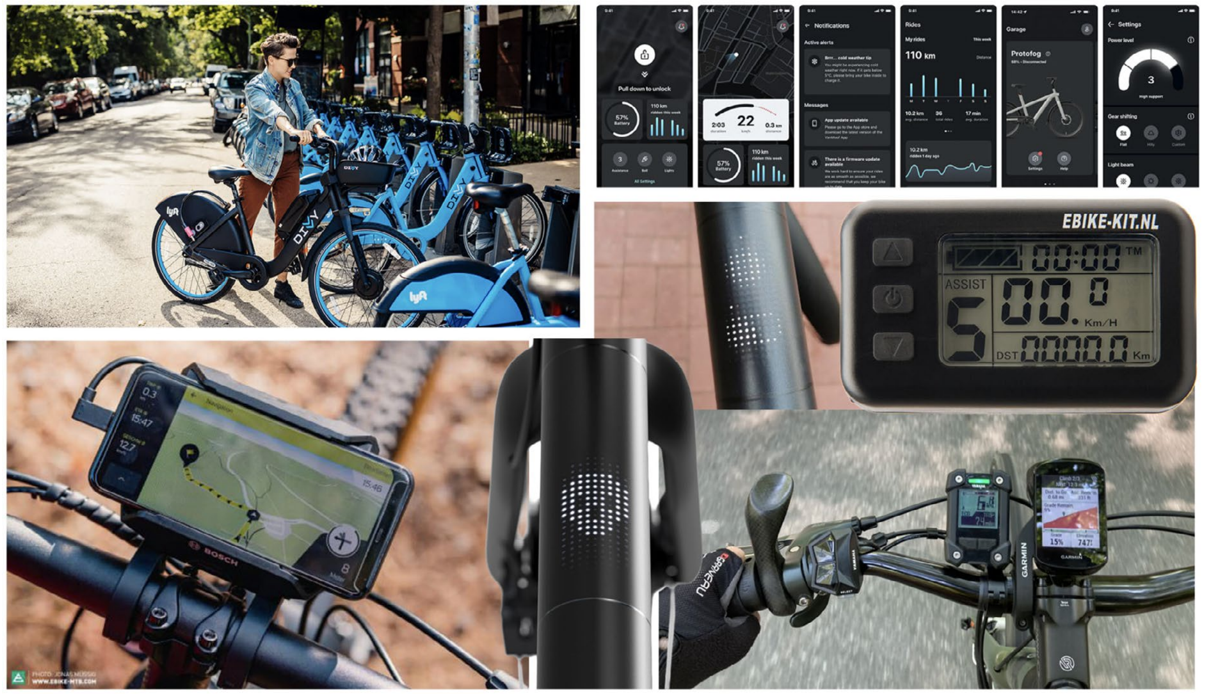


image / figure 1

image / figure 2

Personal Project Brief – IDE Master Graduation Project

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

Urban (e-)bike riders face close passes, busy junctions and frequent distractions. Many current (e-)bike HMIs rely on visual and/or auditory feedback and phone connectivity, which can increase cognitive load and fail in unfavourable conditions.
This graduation project will explore how visual, auditory, and haptic feedback can be combined and adapted to context, to communicate navigation and safety cues with minimal distraction, enhancing the rider's perception and response in mixed traffic scenarios. A key area of investigation will be whether this graduation project can improve the ease of use, intuitiveness and (perceived) safety for the (e-)bike users. The challenge lies in understanding how such feedback can be integrated effectively into the cycling experience and in defining what makes cues clear, distinguishable, and context appropriate.
For (e-)bike users, it could result in safer, more intuitive interaction. For manufacturers and tech companies, it offers a chance to innovate beyond app-based solutions. And for municipalities and safety institutions, it supports efforts to reduce urban traffic incidents by increasing cyclist predictability and awareness without compromising focus on the road.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Design and test a multimodal feedback system to improve ease of use, intuitiveness and (perceived) safety for urban (e-)bike riders, compared to a baseline (e-)bike in mixed traffic city scenarios.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

This project uses an iterative, hands-on approach, working in short Agile sprints with weekly goals and reviews with stakeholders. Starting with Vision in Product (VIP) exercises to frame the intended goals and outcome and turning it into simple design principles.The scope remains open at the start. Specific scenarios, modality mixes, and hardware choices will be refined during the project based on tests and research.
Each sprint cycles: research -> concept -> prototype -> user try-out -> learnings. Early sprints use Wizard-of-Oz (low-fidelity) prototypes to explore the desirability / viability / feasibility of the concept. Later sprints build a high-fidelity prototype.
Evidence comes from small, repeated user tests against hypothesis. The project concludes with a functioning prototype, comparative research that tests whether the product improves the ease of use / intuitiveness / (perceived) safety for the e-bike users and concise design guidelines for applying multimodal feedback on (e-) bikes.

Project planning and key moments

*To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a **kick-off meeting**, **mid-term evaluation meeting**, **green light meeting** and **graduation ceremony**. Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting

Mid-term evaluation

Green light meeting

Graduation ceremony

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	
For how many project weeks	
Number of project days per week	

Comments:

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

My specialty lies in crafting interactive products and systems that engage users and leave a lasting impact. I stay updated with the latest tech trends to enhance user experiences. My work revolves around understanding user needs and ensuring user-friendly products. I'm an advocate for prototyping, have a keen eye for detail, and enjoy tackling complex design challenges.

I want to demonstrate my mastery of the entire industrial design process, from concept to finish, resulting in a working and well-substantiated product. Specifically, I want to demonstrate my competence in mechatronics/electronics, embedded programming, and analytical research, from hypothesis and protocols to clear quantitative evidence.

I am very curious to see how things work in a real design studio and eager to discover the unwritten rules of the design world. Furthermore, I would like to conduct more professional user tests, using good protocols, measurable data and the right tools so the project is substantiated with hard data. Finally, I want to work more systematically, document decisions and keep my workflow consistently up-to-date. I have already improved this considerably during my master's degree, but I want to sharpen those skills even further.

APPENDIX F - MIDTERM EVALUATION FORM

version May 2018

The Midterm Evaluation Form

>> Complete the form to prepare for the midterm evaluation, and send it to your supervisors, at least 3 days prior to your midterm evaluation session. <<

Name student	Luc Jansen
Student number	4824490
Name chair	Stefan Persaud
Name mentor	Joost Alferink

Interim/In-between results

Short description of realised interim results:
<to be filled in by the student>

By the midterm, I delivered a presentation that explains the research exploration, different research directions, the chosen design approach with methodology, my personal learning objectives and a short plan for the next phase. I also shared a global setup of the final report with the supervisory team.

During this period, the project focus shifted from a broad technical exploration to a clearer direction focused on haptic feedback for cyclist safety in B2X-enabled e-bikes. I built an early demonstrator that combines wireless communication, sensing and basic haptic feedback, integrated into bicycle handle grips.

Early tests revealed an important issue, that the vibrations travel through the handlebar, which makes left/right feedback harder to distinguish. This result shows the importance of working iteratively, as it shows a real design problem early on and gives direction for the next project phase.

Reaction on description interim results:
<to be filled in by supervisory team>
Nice progress, good contacts with stakeholders and development of prototypes. Some of the work needs structuring and decision making. Progress is good, start with reporting is required

Reflection[1]
<take the course's learning objectives as starting point when reflecting on the topics below [2]>

Reflection on quality	*<to be filled in by the student>* I have put many efforts into exploration and groundwork, so the quality of the project so far is solid. I have invested a lot of time to understand the context, to involve stakeholders, and define a clear project direction. Also the communication with the supervisors and the external partners has been very good and supportive. There were opportunities to meet renowned stakeholders at work and	*<to be filled in by supervisory team>* Luc is developing good research and design work, what would help increasing the quality is decision making, so more in depth and details can be achieved in the second stage of the project. Also he established a professional working method, towards the project but also

[1] A short indication of your thoughts and considerations with regard to the graduation project up till now.
[2] Learning objectives are to be found in the Course Manual, and in the IDE Study guide.

version May 2018

	even various components for prototyping have been made available, what benefits the quality and relevance of the project. At the same time, the work has been a bit broad rather than deep. In the early phase, too many directions were explored in parallel, which reduced focus and slowed down convergence towards concrete results. While this exploration was valuable, it also limited the level of refinement and evaluation of interim outcomes. The current results show a strong foundation and clear design potential. The scope has already been significantly narrowed towards haptic feedback as the primary focus. The quality will further improve by continuing this focused approach, strengthening method justification and translating explorations into more targeted and well-evaluated design outcomes.	towards the verious (outside) stakeholders.
Reflection on planning	*<to be filled in by the student>* Up to the midterm the planning worked quite well. Most activities for the exploration and definition phase were finished, alignment with stakeholders has been done, problem definition has been mapped out and I started with early prototyping. This shows that a lot of time has been invested in this project. However, the planning was not always very strict. In the first phase, time was divided over too many parallel activities, which made progress less predictable. Some tasks took longer than expected because of the wide scope and technical complexity. Due to this wide scope and technical complexity, will the planning be adjusted a bit. The scope has already been reduced, priorities are made clearer and the next phases will be more structured around clear milestones and deliverables, making the	*<to be filled in by supervisory team>* Making the planning more dynamic and adjusting to unknown opportunities is developing into the good direction. Now the project is becoming more focused and fixed, it will be also more concrete on planning things "smart" keeping control on the graduation as a project. This is an interesting part, planning goes well but for whatever reason, Luc gets sometimes a bit overwhelmed with his own ambitions and tends to get stuck (to his own opinion, not to ours)

version May 2018

	remaining weeks of this graduation project more realistic and manageable.	
Reflection on personal ambitions (if formulated in project brief)	*<to be filled in by the student>* Up to now, this project really fits my personal ambitions. Working on interactive systems matches my interest in user-centred design and technically complex products. I also made quite some leaps in developing my skills in rapid prototyping (3D scanning, modelling and printing), electronics and integrating these electrical systems into 3D printed parts. I also gained experience with working in a professional design environment and managing relationships with different stakeholders. I made progress in working more systematically and keeping better documentation of daily activities. While professional user testing with quantitative or qualitative validation is yet to be done, the basis for structured evaluation is in place. Overall, the project supports my ambition to demonstrate the skills I developed during my master integrated product design so far. Going on, I will focus more strongly on validation and substantiating design decisions.	*<to be filled in by supervisory team>* All good, next steps are validation challenges. Spot on, wondering where your limits lie.
Reflection on supervision and/or project context	*<to be filled in by the student>* The supervision of Joost Alferink and Stefan Persaud have been very supportive so far. Regular contact with them helped me reflect on progress, sharpen the project focus and adjust the scope when needed. Their feedback was especially important in moving from a broad exploration to a more focused and manageable project. The project context at MODYN provided a good and supportive design environment. They have given me access to tools, expertise from different design fields and brought me in connection with external	*<to be filled in by supervisory team>* Good balance between personal connection, academic and company supervisors. Supported with the weekly updates the communication is very continous and reliable.

version May 2018

	partner, providing me with a strong base to deliver a good graduation project Overall, the combination of academic supervision and a professional design studio has had a very positive influence on my project and I am eager to find out what the future will bring.	

Decision supervisory team concerning progress graduation project at this moment

☐ **Continue**	☐ ~~Adjust~~	☐ ~~Discontinue~~

Substantiate the decision:
<to be filled in by supervisory team>

Adjustment of Project Brief: new arrangements

Proposal new arrangements based on this midterm evaluation:
<to be filled in by the student, based on the above reflection. If applicable: add appendices>

Based on the midterm evaluation my project will continue. The scope has already been reduced to *haptic feedback for B2X-enabled e-bikes*, but I have to be more strict on the boundaries of what is in and out of the scope of my project, to prevent the scope from being too broad.

Final arrangements
<describe here the agreed on new arrangements, to be filled in during/after meeting>

To keep the project feasible within the remaining timeframe, my focus will shift from broad exploration towards more narrowed graduation-oriented outcomes. The planning is being refined with clearer milestones, deliverables and decision moments. I will shift my attention a bit more towards writing a clear academic report, supported by visuals and proper documentation. These adjustments are already being implemented and are intended to improve manageability and the overall quality of the final graduation results.

Signatures (name, date and signature of student, chair and mentor)

Name student: Luc Jansen **Date: 19-12-2025**	**Name chair: Stefan Persaud** **Date: 19-12-2025**	**Name mentor: Joost Alferink** **Date: 19-12-2025**

At the end of the Midterm Evaluation meeting: Please hand-in the filled-in form **on Brightspace,** upload to **'IDE Master Graduation Project'** organisation.

APPENDIX G - USER TESTING (INFORM CONSENT FORM)

Informed Consent Form Participant ID: [S: ___] | [P: ___]

User evaluation of a directional haptic warning system in a desktop-based simulated cycling context

This study is conducted as part of a MSc graduation project in Industrial Design Engineering at TU Delft by Luc Joël Jansen (MSc student – TU Delft), under the supervision of Stefan Persaud (Chair – TU Delft), Joost Alferink (Mentor – TU Delft), and Gert-Jan van Breugel (Mentor – MODYN).

Purpose of this research

This study investigates a prototype that communicates possible traffic hazards through vibration. The aim is to evaluate whether directional haptic feedback via vibrating handlebars and a vibrating helmet is experienced as an acceptable interaction modality in a desktop-based simulated cycling context, with specific attention to workload, usefulness, satisfaction, clarity, perceived safety, and irritation.

Informed consent participant

I acknowledge that I have received sufficient information and explanation about the research, and that all my questions have been answered satisfactorily. I was given sufficient time to decide on my participation. I understand that I can ask further questions at any moment during the research.

I am aware that this research visit consists of the following activities:

- completing a short pre-test questionnaire;
- wearing a prototype helmet and using a prototype handlebar interface;
- taking part in a short calibration and practice round;
- watching short traffic video scenarios on a monitor;
- responding to haptic warning cues from the prototypes;
- completing a post-test questionnaire;
- answering a few short debrief questions.

I am aware that data may be collected during the study in the form of questionnaire responses, observational notes, interview responses, and digitally logged response data such as reaction times and response behaviour. No video or audio recordings will be made. The collected data will be pseudonymised so that my name is not directly linked to the research dataset.

Informed Consent Form Participant ID: [S: ___] | [P: ___]

I give permission for collecting:

☐ Data in the form of answered questionnaires during the study

☐ Data in the form of notes taken during the study

☐ Data in the form of interview responses during the study

☐ Data in the form of digitally logged response data during the study

The data collected during this study will be used for Luc Jansen's Master's graduation project at TU Delft, within the Integrated Product Design programme. The results may also be used for academic reporting, thesis assessment, and educational or research purposes within TU Delft. The final Master's thesis will be published by TU Delft in the **TU Delft Master's Thesis Repository**. MODYN and Gazelle may access the thesis through TU Delft after publication and will therefore only have access to the information included in the published thesis.

I understand that no direct identifying participant data will be shared with external parties. Any sharing of findings during the project will take place only in aggregated or de-identified form.

I give permission for the collected data to be stored on TU Delft OneDrive for a maximum of 10 years after the completion of this research, for research and educational purposes related to this project.

I understand that participation is voluntary and that I may withdraw from the study at any time, without giving a reason and without negative consequences. I also understand that I am not obliged to answer any question that I prefer not to answer.

I understand that I may request deletion of my identifiable or linkable data until **April 9th 2026**. After that point, the remaining research dataset will be treated as pseudonymised / non-directly identifiable.

I acknowledge that no financial compensation will be provided for my participation in this research.

With my signature, I confirm that I have read and understood the information provided about this research and that I consent to participate in this study.

________________________ ________________________

Last name First name

____ / ____ / ___

Date (dd / mm / yyyy) Signature

APPENDIX H - USER TESTING (STEP-BY-STEP PLAN)

Stappenplan V5

Setup

> Remember to charge the prototypes and bring backup parts.

Equipment

- desk
- chair
- ultrawide monitor
- laptop
- HDMI or Thunderbolt connection
- Wi-Fi router
- gateway Arduino
- handlebar prototype + backup parts
- helmet prototype + backup parts
- USB-C cables
- power strip
- drinks / water
- printed instructions
- informed consent forms
- NASA-TLX forms
- Van der Laan scale forms
- participant questionnaire forms
- trial observation sheets
- qualitative interview sheet
- plastic folder per participant

Folder per participant

For each participant, I want to prepare one plastic folder containing:

1. participant information + consent form
2. demographic and background questionnaire
3. pre-test Van der Laan scale
4. trial notes sheet
5. NASA-TLX sheet
6. post-test Van der Laan scale
7. qualitative interview sheet
8. optional blank note page

1. Welcome

The researcher welcomes the participant and briefly explains:

- that the study is about the prototype, not about testing the participant;
- that participation is voluntary;
- that the participant will remain seated during the session;
- that the session will take approximately [XX minutes].

2. Inform about the research

Let participants read the Inform about the research file, or read it to them

3. Informed consent + participant ID

The researcher will:

- provide the participant information and consent form;
- answer questions;
- obtain signed consent;
- assign a participant ID;
- write that participant ID on all non-consent sheets.

3. Explaining functionality

Before we begin, I will briefly explain how the test and the prototypes work.

During the test, you will be shown short videos of different traffic situations. These are not real recordings, but simulated scenarios in mixed traffic. You will see the situation from the perspective of a cyclist.

It is important to know that the video will continue playing even if you brake. So your braking action does not affect what happens in the video. I use your response mainly to understand how you interpret the warnings and how you naturally react to them.

You will use two haptic prototypes: a helmet and a handlebar interface. Both are able to provide vibration cues.

The **helmet** provides directional vibration cues around the head. The helmet also uses **head tracking**. This means that the system takes into account the direction in which you are looking, so that the vibration remains linked to the direction of the possible hazard relative to your head orientation. The vibration cues are intended to indicate from which direction a possible hazard is approaching. The vibration patterns may also differ, for example as a local vibration at one position or more as a movement along the side of the head.

The **handlebar interface** also provides directional vibration cues, through the left or right side of the handlebar. These cues are also intended to indicate the direction of a possible hazard. Here too, the vibration patterns may differ, for example continuous or pulsing.

Not every trial contains the same type of feedback. In some trials, you may receive feedback through the helmet, in others through the handlebars, and in some trials there may be no haptic feedback.

During the test, I would like to ask you to respond as naturally as possible to the situation, in the way you would normally react on a bicycle when you notice a potential hazard. This also means that, if you feel the situation calls for it, I would like you to brake in the way you normally would on a real bicycle.

There is no single fixed or correct braking strategy that I want you to use. I am interested in how you interpret the warning and how you naturally respond to it.

If possible, I would also appreciate it if you could occasionally say out loud what you think is happening, or where you think the hazard is coming from. That helps me to better understand how you interpret the situation and the warning. It does not have to be perfect or constant, but if it is possible, it is very valuable.

So please try to respond in a way that feels as realistic and natural as possible.

And if anything still feels unclear during the practice round, I can of course explain it further before the real test begins.

Nederlands

Voordat we beginnen, leg ik kort uit hoe de test en de prototypes werken.

Tijdens de test krijgt u korte filmpjes te zien van verschillende verkeerssituaties. Dit zijn geen echte beelden, maar gesimuleerde scenario's in gemengd verkeer. U ziet de situatie vanuit het perspectief van een fietser.

Het is goed om te weten dat het filmpje gewoon blijft doorspelen, ook als u remt. Uw remactie heeft dus geen invloed op wat er in het filmpje gebeurt. Ik gebruik uw reactie vooral om te zien hoe u de waarschuwingen interpreteert en hoe u daar van nature op reageert.

U gaat twee haptische prototypes gebruiken: een helm en een stuurinterface. Beide kunnen trillingen geven.

De **helm** geeft directionele trillingen rondom het hoofd. De helm gebruikt daarbij ook **headtracking**. Dat betekent dat het systeem rekening houdt met de richting waarin u kijkt, zodat de trilling gekoppeld blijft aan de richting van het mogelijke gevaar ten opzichte van uw hoofdoriëntatie. De trillingen zijn bedoeld om aan te geven uit welke richting een mogelijk gevaar nadert. De trillingen kunnen ook in patroon verschillen, bijvoorbeeld lokaal op één plek of meer als een beweging langs de zijkant van het hoofd.

De **stuurinterface** geeft ook directionele trillingen, via de linker- of rechterkant van het stuur. Ook die trillingen zijn bedoeld om de richting van een mogelijk gevaar aan te geven. Ook hier kunnen de trillingen in patroon verschillen, bijvoorbeeld continu of pulserend.

Niet elke trial bevat hetzelfde type feedback. In sommige trials krijgt u feedback via de helm, in andere via het stuur, en in sommige trials krijgt u geen haptische feedback.

Tijdens de test wil ik u vragen om zo natuurlijk mogelijk op de situatie te reageren, dus zoals u dat normaal gesproken op een fiets ook zou doen wanneer u een mogelijk gevaar opmerkt. Dat betekent ook dat, als u denkt dat het nodig is, ik u wil vragen te remmen zoals u dat op een echte fiets normaal ook zou doen.

Er is daarbij niet één vaste of juiste manier van remmen die u moet gebruiken. Ik ben juist geïnteresseerd in hoe u de waarschuwing interpreteert en hoe u daar van nature op reageert.

Als het lukt, zou ik het ook fijn vinden als u af en toe kort hardop zegt wat u denkt dat er gebeurt, of waar u denkt dat het gevaar vandaan komt. Dat helpt mij om beter te begrijpen hoe u de situatie en de waarschuwing interpreteert. Het hoeft niet perfect of de hele tijd, maar als het lukt is dat heel waardevol.

Probeer dus vooral zo realistisch en natuurlijk mogelijk te reageren.

En als er tijdens de oefenronde nog iets onduidelijk is, dan kan ik dat natuurlijk nog toelichten voordat de echte test begint.

5. Van der Laan scale — first measurement

Before the practice rounds, the researcher briefly introduces the system concept and ask the participant to complete the Van der Laan scale based on their first expectation of the system.

This allows this study to compare expected acceptance before use with experienced acceptance after use.

6. Gathering initial information

Questionair file

7. Calibrating helmet

- place the helmet correctly;
- ask the participant to look forward;
- reset the system;
- start calibration;
- verify whether the head tracking and haptic output work correctly.

8. Practice rounds

Before the real test starts, participants need to complete a short practice phase.

Planned practice

- 4 practice trials
- both scenario families included
- at least one helmet cue and one handlebar cue
- practice data not used in the final analysis

The practice is meant to:

- get participants used to the setup;
- reduce first-exposure confusion;
- make the main trials more stable.

9. Main trials

The number of main trials will be kept deliberately limited, as the primary aim of the study is to support participant experience and reflection rather than extensive behavioural testing. Each trial will consist of one selected traffic event combined with one selected feedback modality. In this way, participants will experience a focused set of representative combinations of scenario type, hazard direction, and feedback condition.

Event 1: Car from front-left

- video: intersection, car from left
- feedback:
  - none
  - handlebars only: left handle continuous
  - helmet only: left pulsing local cue

Event 2: Car from front-right

- video: intersection, car from right
- feedback:
  - none
  - handlebars only: right handle continuous
  - helmet only: right pulsing local cue

Event 3: Cyclist from rear-left

- video: overtaking from left behind
- feedback:
  - none
  - handlebars only: left handle pulsing
  - helmet only: left sweep

What is logged digitally

- reaction time
- brake input
- brake side

What I record on paper per trial

I want to keep the paper observations short and practical.

Researcher observation

- correct interpretation? yes / no
- missed response? yes / no
- visible hesitation / confusion: none / slight / clear
- extra note

10. NASA-TLX

After the full trial block, I want the participant to complete the NASA-TLX on paper.

11. Van der Laan scale — second measurement

After participants have actually experienced the prototype, I want them to complete the Van der Laan scale again.

This allows me to compare:

- expected usefulness and satisfaction before use,
- experienced usefulness and satisfaction after use.

12. Qualitative feedback

After the questionnaires, I want to ask a short set of qualitative questions.

Questions

1. Which warnings were easiest to understand?
2. Which warnings were most confusing?
3. Did the helmet or the handlebars feel more directionally clear?
4. Did either prototype influence how you braked?
5. Did the warnings feel helpful, stressful, or irritating?
6. Did the system increase your sense of safety or control?
7. Would you want to use a system like this in daily cycling?
8. What about the prototypes did you like and/or dislike?
9. What would you improve?
10. How was the overall experience for you?

13. Wrapping up and thanking participants

At the end of the session, the researcher:

- thanks the participant;
- explains what happens with the data;
- reminds them of the withdrawal deadline [April 9th];
- separates the consent form from the research data;
- stores all materials correctly.

APPENDIX I - USER TESTING (DOCUMENT TO INFORM PARTICIPANTS ABOUT THE RESEARCH)

User evaluation of a directional haptic warning system in a desktop-based simulated cycling context

Thank you for taking part in this study.

This study is part of my Master's graduation project at TU Delft. The purpose of this study is to evaluate a prototype that communicates possible traffic hazards through vibration. More specifically, I am investigating how directional haptic feedback is experienced in a desktop-based simulated cycling context.

The prototype is related to the idea of **B2X communication**. B2X stands for communication between a bicycle and its surroundings, for example other vehicles, cyclists, or infrastructure. In the future, systems like this could be used to detect relevant traffic situations and provide warnings to road users. My prototype focuses specifically on how such warnings could be communicated to cyclists through directional vibration, using a helmet and handlebars.

During this session, you will remain seated at a desk in front of a monitor. You will wear a prototype helmet and place your hands on a prototype handlebar interface. You will then watch a short set of simulated traffic scenarios on the monitor. During some of these scenarios, the system may provide directional haptic warning cues through vibration.

The aim of this study is not to test you, but to evaluate the prototype and how it is experienced. I am interested in whether the feedback feels understandable, useful, acceptable, and not too mentally demanding. I am also interested in how clear the feedback feels, whether it affects your sense of safety or control, and whether it feels irritating or not.

During the session, I will collect several types of data. These may include your questionnaire responses, my observations during the test, and supportive digital response data from the system, such as reaction time and brake input. No video or audio recordings will be made.

Participation is entirely voluntary. You may stop at any moment without giving a reason, and you may also choose not to answer any question if you prefer not to.

Before we begin, I will first ask you to read and sign the consent form. After that, I will assign you a participant ID and continue with the short background questionnaire and the rest of the session.

Do you have any questions before we continue?

User evaluation of a directional haptic warning system in a desktop-based simulated cycling context

Bedankt voor uw deelname aan deze studie.

Deze studie maakt deel uit van mijn masterafstudeerproject aan de TU Delft. Het doel van deze studie is om een prototype te evalueren dat mogelijke verkeersgevaren communiceert via trillingen. Meer specifiek onderzoek ik hoe directionele haptische feedback wordt ervaren in een desktop-gebaseerde gesimuleerde fietscontext.

Het prototype is gerelateerd aan het idee van **B2X-communicatie**. B2X staat voor communicatie tussen een fiets en zijn omgeving, bijvoorbeeld andere voertuigen, fietsers of infrastructuur. In de toekomst zouden systemen zoals deze gebruikt kunnen worden om relevante verkeerssituaties te detecteren en waarschuwingen te geven aan weggebruikers. Mijn prototype richt zich specifiek op hoe zulke waarschuwingen aan fietsers gecommuniceerd kunnen worden via directionele trillingen, met behulp van een helm en een stuur.

Tijdens deze sessie blijft u zitten aan een bureau voor een monitor. U draagt een prototypehelm en plaatst uw handen op een prototype-stuurinterface. Vervolgens bekijkt u op de monitor een korte reeks gesimuleerde verkeersscenario's. Tijdens sommige van deze scenario's kan het systeem directionele haptische waarschuwingssignalen geven via trillingen.

Het doel van deze studie is niet om u te testen, maar om het prototype en de manier waarop het wordt ervaren te evalueren. Ik ben geïnteresseerd in de vraag of de feedback begrijpelijk, bruikbaar, acceptabel en niet te mentaal belastend aanvoelt. Daarnaast ben ik geïnteresseerd in hoe duidelijk de feedback aanvoelt, of deze invloed heeft op uw gevoel van veiligheid of controle, en of deze als storend wordt ervaren of niet.

Tijdens de sessie verzamel ik verschillende soorten gegevens. Deze kunnen onder andere bestaan uit uw antwoorden op vragenlijsten, mijn observaties tijdens de test en ondersteunende digitale responsgegevens van het systeem, zoals reactietijd en reminput. Er worden geen video- of audio-opnames gemaakt.

Deelname is volledig vrijwillig. U kunt op elk moment stoppen zonder daarvoor een reden te geven. Ook kunt u ervoor kiezen om een vraag niet te beantwoorden als u dat liever niet doet.

Voordat we beginnen, vraag ik u eerst om het toestemmingsformulier te lezen en te ondertekenen. Daarna ken ik u een deelnemers-ID toe en gaan we verder met de korte achtergrondvragenlijst en de rest van de sessie.

Heeft u nog vragen voordat we verdergaan?

APPENDIX J - USER TESTING (QUESTIONAIR)

Questionair (Vragenlijst) Participant ID: [S: ___] | [P: ___]

Demographic

- **Age category**

18–29 / 30–44 / 45–59 / 60–74 / 75+

- **Gender**

male / female / non-binary / prefer not to say

Cycling profile

- **How often do you use your bicycle?**

daily / several times per week / once per week / less than once per week / almost never

- **Approximately how many km do you cycle per week?**

0–10 / 11–25 / 26–50 / 51–100 / 100+

- **Do you usually use an e-bike?**

yes / no / sometimes

- **Do you wear a bicycle helmet while cycling?**

always / often / sometimes / rarely / never

- **What helmet size do you normally wear, if any?**

S / M / L / other / I do not normally wear a helmet

- **How does this prototype helmet fit you?**

too small / good fit / too large

Experience with traffic and cycling

- **How confident do you normally feel as a cyclist in traffic?**

Unsure (O O O O O) Very confident

- **How often do you experience a startle situation while cycling?**

Almost never (O O O O O) Very often

Questionair (Vragenlijst) Participant ID: [S: ___] | [P: ___]

- **Do you often look over your shoulder while cycling when in doubt or when being overtaken?**

often / sometimes / rarely / never / I use a mirror

- **Do you listen to music, podcasts, or other audio while cycling?**

often / sometimes / rarely / never

- **If yes, how do you usually listen while cycling?**

one earbud / two earbuds / headphones / other

Familiarity with feedback systems

- **Have you used systems with vibrating warnings before?**

yes / no

- **Do you have a screen or display on your bicycle?**

yes / no

- **Do you use navigation while cycling?**

often / sometimes / rarely / never

- **If yes, how do you usually use navigation while cycling?**

screen on bicycle / smartphone on handlebar / audio instructions / smartwatch / other

- **Do you sometimes feel distracted by screens or navigation while cycling?**

often / sometimes / rarely / never

Discomfort

- **Are you sensitive to vibrations or easily irritated by vibrating alerts?**

yes / no / not sure

- **Are you currently experiencing physical symptoms that make head movements or quick responses uncomfortable?**

yes / no / prefer not to say

APPENDIX K - USER TESTING (VAN DER LAAN & NASA-TLX FORM)

Van der Laan & NASA-TLX Participant ID: [S: ___] | [P: ___]

Before testing

Please tick a box on every line.

I find such a system...

1. Useful |__|__|__|__|__| Useless
2. Pleasant |__|__|__|__|__| Unpleasant
3. Bad |__|__|__|__|__| Good
4. Nice |__|__|__|__|__| Annoying
5. Effective |__|__|__|__|__| Superfluous
6. Irritating |__|__|__|__|__| Likeable
7. Assisting |__|__|__|__|__| Worthless
8. Undesirable |__|__|__|__|__| Desirable
9. Raising Alertness |__|__|__|__|__| Sleep-inducing

After testing

Please tick a box on every line.

I find such a system...

1. Useful |__|__|__|__|__| Useless
2. Pleasant |__|__|__|__|__| Unpleasant
3. Bad |__|__|__|__|__| Good
4. Nice |__|__|__|__|__| Annoying
5. Effective |__|__|__|__|__| Superfluous
6. Irritating |__|__|__|__|__| Likeable
7. Assisting |__|__|__|__|__| Worthless
8. Undesirable |__|__|__|__|__| Desirable
9. Raising Alertness |__|__|__|__|__| Sleep-inducing

Van der Laan & NASA-TLX Participant ID: [S: ___] | [P: ___]

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

APPENDIX L - USER TESTING (TRIAL NOTES)

Observations Participant ID: [S: ___] | [P: ___]

1. **Trial:** ____

correct interpretation: yes / no
missed response: yes / no
visible hesitation / confusion: none / slight / clear
extra note:

____

____

2. **Trial:** ____

correct interpretation: yes / no
missed response: yes / no
visible hesitation / confusion: none / slight / clear
extra note:

____

____

3. **Trial:** ____

correct interpretation: **yes / no**
missed response: **yes / no**
visible hesitation / confusion: **none / slight / clear**
extra note:

____

____

4. **Trial:** ____

correct interpretation: yes / no
missed response: yes / no
visible hesitation / confusion: none / slight / clear
extra note:

____

____

5. **Trial:** ____

correct interpretation: yes / no
missed response: yes / no
visible hesitation / confusion: none / slight / clear
extra note:

____

____

Observations Participant ID: [S: ___] | [P: ___]

6. **Trial:** ____

correct interpretation: yes / no
missed response: yes / no
visible hesitation / confusion: none / slight / clear
extra note:

____

____

7. **Trial:** ____

correct interpretation: yes / no
missed response: yes / no
visible hesitation / confusion: none / slight / clear
extra note:

____

____

8. **Trial:** ____

correct interpretation: yes / no
missed response: yes / no
visible hesitation / confusion: none / slight / clear
extra note:

____

____

9. **Trial:** ____

correct interpretation: yes / no
missed response: yes / no
visible hesitation / confusion: none / slight / clear
extra note:

____

____

10. **Trial:** ____

correct interpretation: yes / no
missed response: yes / no
visible hesitation / confusion: none / slight / clear
extra note:

____

____

Observations Participant ID: [S: ___] | [P: ___]

11. Trial: ____________________________________
correct interpretation: yes / no
missed response: yes / no
visible hesitation / confusion: none / slight / clear
extra note:
____
____

12. Trial: ____________________________________
correct interpretation: yes / no
missed response: yes / no
visible hesitation / confusion: none / slight / clear
extra note:
____
____

13. Trial: ____________________________________
correct interpretation: yes / no
missed response: yes / no
visible hesitation / confusion: none / slight / clear
extra note:
____
____

14. Trial: ____________________________________
correct interpretation: yes / no
missed response: yes / no
visible hesitation / confusion: none / slight / clear
extra note:
____
____

15. Trial: ____________________________________
correct interpretation: yes / no
missed response: yes / no
visible hesitation / confusion: none / slight / clear
extra note:
____
____

Observations Participant ID: [S: ___] | [P: ___]

Notes:

APPENDIX M - USER TESTING (INTERVIEW QUESTIONS)

Questions | Participant ID: | [S: ___] | [P: ___]

Which warnings were easiest to understand?

____

____

Which warnings were most confusing?

____

____

Did the helmet or the handlebars feel more directionally clear?

____

____

Did either prototype influence how you braked?

____

____

Did the warnings feel helpful, stressful, or irritating?

____

____

Did the system increase your sense of safety or control?

____

____

Questions | Participant ID: | [S: ___] | [P: ___]

Would you want to use a system like this in daily cycling?

____

____

What about the prototypes did you like and/or dislike?

____

____

What would you improve?

____

____

How was the overall experience for you?

____

____

APPENDIX N - HREC CHECKLIST

Delft University of Technology
HUMAN RESEARCH ETHICS
CHECKLIST FOR HUMAN RESEARCH
(Version January 2022)

IMPORTANT NOTES ON PREPARING THIS CHECKLIST

1. An HREC application should be submitted for every research study that involves human participants (as Research Subjects) carried out by TU Delft researchers
2. Your HREC application should be submitted and approved **before** potential participants are approached to take part in your study
3. All submissions from Master's Students for their research thesis need approval from the relevant Responsible Researcher
4. The Responsible Researcher must indicate their approval of the completeness and quality of the submission by signing and dating this form OR by providing approval to the corresponding researcher via email (included as a PDF with the full HREC submission)
5. There are various aspects of human research compliance which fall outside of the remit of the HREC, but which must be in place to obtain HREC approval. These often require input from internal or external experts such as Faculty Data Stewards, Faculty HSE advisors, the TU Delft Privacy Team or external Medical research partners.
6. You can find detailed guidance on completing your HREC application here
7. Please note that incomplete submissions (whether in terms of documentation or the information provided therein) will be returned for completion **prior to any assessment**
8. If you have any feedback on any aspect of the HREC approval tools and/or process you can leave your comments here

I. Applicant Information

PROJECT TITLE:	**User evaluation of a directional haptic warning system in a desktop-based simulated cycling context**
Research period: *Over what period of time will this specific part of the research take place*	**April 2026**
Faculty:	**Faculty of Industrial Design Engineering (IDE)**
Department:	**SDE**
Type of the research project: *(Bachelor's, Master's, DreamTeam, PhD, PostDoc, Senior Researcher, Organisational etc.)*	**Master's Graduation Project**
Funder of research: *(EU, NWO, TUD, other – in which case please elaborate)*	**Other, TU Delft Master's graduation project with external advisory involvement from MODYN**
Name of Corresponding Researcher: *(If different from the Responsible Researcher)*	**Luc Joël Jansen**
E-mail Corresponding Researcher: *(If different from the Responsible Researcher)*	
Position of Corresponding Researcher: *(Masters, DreamTeam, PhD, PostDoc, Assistant/ Associate/ Full Professor)*	**Masters**
Name of Responsible Researcher: ***Note:*** *all student work must have a named Responsible Researcher to approve, sign and submit this application*	**Stefan Persaud**
E-mail of Responsible Researcher: *Please ensure that an institutional email address (**no Gmail, Yahoo, etc.**) is used for all project documentation/ communications including Informed Consent materials*	
Position of Responsible Researcher : *(PhD, PostDoc, Associate/ Assistant/ Full Professor)*	**Chair**

II. Research Overview

NOTE: You can find more guidance on completing this checklist here

a) Please summarise your research very briefly (100-200 words)
What are you looking into, who is involved, how many participants there will be, how they will be recruited and what are they expected to do?

Add your text here – (please avoid jargon and abbrevations)
This study evaluates a directional haptic warning prototype in a controlled desktop-based simulated cycling context. The research is conducted as part of a TU Delft Master's graduation project. Adult participants will be recruited as volunteers at the Gazelle Experience Center in Dieren. The preferred participant group consists of cyclists aged 60 and above, although participants aged 40+ or 50+ may also be included if necessary. During the study, participants will remain seated at a desk in front of a monitor and will not ride a real bicycle or be exposed to live traffic. They will wear a prototype helmet and use a prototype handlebar interface while watching short simulated traffic scenarios. During these scenarios, the system provides directional haptic warning cues through vibration. The study focuses on how acceptable this interaction modality is in terms of perceived workload, usefulness, satisfaction, clarity, perceived safety, and irritation. Data collected may include questionnaire responses, interview responses, researcher observation notes, and supportive behavioural response data such as reaction time and brake input. No video or audio recordings will be made.

b) **If your application is an additional project** related to an existing approved HREC submission, please provide a brief explanation including the existing relevant HREC submission number/s.

Add your text here – (please avoid jargon and abbrevations)
Not applicable

c) **If your application is a simple extension of, or amendment to,** an existing approved HREC submission, you can simply submit an HREC Amendment Form as a submission through LabServant.

III. Risk Assessment and Mitigation Plan

NOTE: You can find more guidance on completing this checklist here

Please complete the following table in full for all points to which your answer is "yes". Bear in mind that the vast majority of projects involving human participants as Research Subjects also involve the collection of **Personally Identifiable Information (PII)** and/or **Personally Identifiable Research Data (PIRD)** which may pose potential risks to participants as detailed in Section G: Data Processing and Privacy below.

To ensure alighment between your risk assessment, data management and what you agree with your Research Subjects you can use the last two columns in the table below to refer to specific points in your Data Management Plan (DMP) and Informed Consent Form (ICF) – **but this is not compulsory**.

It's worth noting that **you're much more likely to need to resubmit your application if you neglect to identify potential risks**, than if you identify a potential risk and demonstrate how you will mitigate it. If necessary, the HREC will always work with you and colleagues in the Privacy Team and Data Management Services to see how, if at all possible, your research can be conducted.

			If YES please complete the Risk Assessment and Mitigation Plan columns below.		*Please provide the relevant reference #*	
ISSUE	**Yes**	**No**	**RISK ASSESSMENT – what risks could arise?** *Please ensure that you list ALL of the actual risks that could potentially arise – do not simply state whether you consider any such risks are important!*	**MITIGATION PLAN – what mitigating steps will you take?** *Please ensure that you summarise what actual mitigation measures you will take for each potential risk identified – do not simply state that you will e.g. comply with regulations.*	**DMP**	**ICF**
A: Partners and collaboration						
1. Will the research be carried out in collaboration with additional organisational partners such as: • One or more collaborating research and/or commercial organisations • Either a research, or a work experience internship provider[1] *[1] If yes, please include the graduation agreement in this application*	x		The project includes external advisory involvement from MODYN and has an interested external stakeholder context through Gazelle. The study will take place at the Gazelle Experience Center in Dieren. Risks may arise if the role of external parties is unclear, for example regarding participant access, study influence, or access to research outputs.	The study is conducted under TU Delft academic responsibility. TU Delft is responsible for the HREC application, the informed consent process, and the management of participant-related data. MODYN provides expertise and feedback only. Gazelle is an interested stakeholder in the broader project context and provides the testing context at the Gazelle Experience Center, but is not the responsible research institution. No direct identifying participant data will be shared with external parties. Any sharing of findings during the project will take place only in aggregated or de-identified form. The final Master's thesis will be published by TU Delft in the TU Delft Master's Thesis Repository. Following publication, MODYN and Gazelle may access the thesis via TU Delft and will therefore		

			If YES please complete the Risk Assessment and Mitigation Plan columns below.		*Please provide the relevant reference #*	
ISSUE	**Yes**	**No**	**RISK ASSESSMENT – what risks could arise?** *Please ensure that you list ALL of the actual risks that could potentially arise – do not simply state whether you consider any such risks are important!*	**MITIGATION PLAN – what mitigating steps will you take?** *Please ensure that you summarise what actual mitigation measures you will take for each potential risk identified – do not simply state that you will e.g. comply with regulations.*	**DMP**	**ICF**
				only have access to the information contained in the published thesis.		
2. Is this research dependent on a Data Transfer or Processing Agreement with a collaborating partner or third party supplier? *If yes please provide a copy of the signed DTA/DPA*		x				
3. Has this research been approved by another (external) research ethics committee (e.g.: HREC and/or MREC/METC)? *If yes, please provide a copy of the approval (if possible) and summarise any key points in your Risk Management section below*		x				
B: Location						
4. Will the research take place in a country or countries, other than the Netherlands, within the EU?		x				
5. Will the research take place in a country or countries outside the EU?		x				
6. Will the research take place in a place/region or of higher risk – including known dangerous locations (in any country) or locations with non-democratic regimes?		x				
C: Participants						
7. Will the study involve participants who **may** be vulnerable and possibly (legally) unable to give informed consent? (e.g., children below the legal age for giving consent, people with learning difficulties, people living in care or nursing homes,).		x				
8. Will the study involve participants who **may** be vulnerable under specific circumstances and in specific contexts, such as victims and witnesses of violence, including domestic violence; sex workers; members of minority groups, refugees, irregular migrants or dissidents?		x				
9. Are the participants, outside the context of the research, in a dependent or subordinate position to the investigator (such as own children, own students or employees of either TU Delft and/or a collaborating partner organisation)? *It is essential that you safeguard against possible adverse consequences of this situation (such as allowing a student's failure to participate to your satisfaction to affect your evaluation of their coursework).*		x				
10. Is there a high possibility of re-identification for your participants? (e.g., do they have a very specialist job of which there are only a small number in a given country, are they members of a small community, or employees from a		x				

			If YES please complete the Risk Assessment and Mitigation Plan columns below.		*Please provide the relevant reference #*	
ISSUE	**Yes**	**No**	**RISK ASSESSMENT – what risks could arise?** *Please ensure that you list ALL of the actual risks that could potentially arise – do not simply state whether you consider any such risks are important!*	**MITIGATION PLAN – what mitigating steps will you take?** *Please ensure that you summarise what actual mitigation measures you will take for each potential risk identified – do not simply state that you will e.g. comply with regulations.*	**DMP**	**ICF**
19. Will the study involve discussion of personal sensitive data which could put participants at increased legal, financial, reputational, security or other risk? (e.g., financial data, location data, data relating to children or other vulnerable groups) *Definitions of sensitive personal data, and special cases are provided on the TUD Privacy Team website.*		x				
20. Will the study involve disclosing commercially or professionally sensitive, or confidential information? (e.g., relating to decision-making processes or business strategies which might, for example, be of interest to competitors)		x				
21. Has your study been identified by the TU Delft Privacy Team as requiring a Data Processing Impact Assessment (DPIA)? *If yes please attach the advice/ approval from the Privacy Team to this application*		x				
22. Does your research investigate causes or areas of conflict? *If yes please confirm that your fieldwork has been discussed with the appropriate safety/security advisors and approved by your Department/Faculty.*		x				
23. Does your research involve observing illegal activities or data processed or provided by authorities responsible for preventing, investigating, detecting or prosecuting criminal offences *If so please confirm that your work has been discussed with the appropriate legal advisors and approved by your Department/Faculty.*		x				
F: Research Methods						
24. Will it be necessary for participants to take part in the study without their knowledge and consent at the time? (e.g., covert observation of people in non-public places).		x				
25. Will the study involve actively deceiving the participants? (For example, will participants be deliberately falsely informed, will information be withheld from them or will they be misled in such a way that they are likely to object or show unease when debriefed about the study).		x				
26. Is pain or more than mild discomfort likely to result from the study? And/or could your research activity cause an accident involving (non-) participants?		x				
27. Will the experiment involve the use of devices that are not 'CE' certified? *Only, if 'yes': continue with the following questions:*	x		The study uses a prototype system assembled from commonly used components that are normally used in a safe and standard manner. Based on the intended use during the test, the setup is expected	The prototype will only be used in a seated, desk-based simulation and will not be used in live traffic or on a real bicycle. The setup will be checked before each session to ensure normal operation. The researcher		

			If YES please complete the Risk Assessment and Mitigation Plan columns below.		*Please provide the relevant reference #*	
ISSUE	**Yes**	**No**	**RISK ASSESSMENT – what risks could arise?** *Please ensure that you list ALL of the actual risks that could potentially arise – do not simply state whether you consider any such risks are important!*	**MITIGATION PLAN – what mitigating steps will you take?** *Please ensure that you summarise what actual mitigation measures you will take for each potential risk identified – do not simply state that you will e.g. comply with regulations.*	**DMP**	**ICF**
			to involve low physical risk. Potential discomfort is limited mainly to mild physical discomfort, brief mild surprise due to vibration, or minor inconvenience associated with wearing or using the prototype hardware.	will supervise the participant throughout the session. Participants may pause or stop the study immediately if they experience discomfort. The components are used in a controlled indoor setting and handled in a normal and careful manner throughout the test sessions.		
• Was the device built in-house?	x		*The prototype may cause mild discomfort, brief surprise due to vibration, or minor inconvenience during use. No live traffic or real bicycle use is involved, and no hazardous use conditions are expected in the planned test setup.*	*The prototype is handled in a normal, careful, and controlled manner throughout the study. No hazardous situations are involved in the intended use of the setup. The system is checked before each session, supervised by the researcher during use, and participants may stop immediately if discomfort occurs. The intended use of the prototype and test setup has been discussed with the Chair of the graduation project, who considered it a low-risk and non-hazardous prototype for the purpose of this study.*		
• Was it inspected by a safety expert at TU Delft? *If yes, please provide a signed device report*		x				
• If it was not built in-house and not CE-certified, was it inspected by some other, qualified authority in safety and approved? *If yes, please provide records of the inspection*						
28. Will your research involve face-to-face encounters with your participants and if so how will you assess and address Covid considerations?	x		The study involves in-person interaction and shared use of prototype equipment in an indoor setting.	The session will take place in a controlled indoor environment. Shared contact surfaces will be cleaned with disinfectant where relevant between sessions. Each participant will receive a personal hairnet for use with the helmet prototype. Participation will only take place when both the participant and the researcher are fit to attend. Basic hygiene precautions will be followed throughout the study.		
29. Will your research involve **either:** a) "big data", combined datasets, new data-gathering or new data-merging techniques which might lead to re-identification of your participants **and/or** b) artificial intelligence or algorithm training where, for example biased datasets could lead to biased outcomes?		x				
G: Data Processing and Privacy						

			If YES please complete the Risk Assessment and Mitigation Plan columns below.		*Please provide the relevant reference #*	
ISSUE	**Yes**	**No**	**RISK ASSESSMENT – what risks could arise?** *Please ensure that you list ALL of the actual risks that could potentially arise – do not simply state whether you consider any such risks are important!*	**MITIGATION PLAN – what mitigating steps will you take?** *Please ensure that you summarise what actual mitigation measures you will take for each potential risk identified – do not simply state that you will e.g. comply with regulations.*	**DMP**	**ICF**
30. Will the research involve collecting, processing and/or storing any directly identifiable PII (Personally Identifiable Information) including name or email address that will be used for administrative purposes only? (eg: obtaining Informed Consent or disbursing remuneration)	x		The study involves collecting directly identifiable administrative data on consent forms, including the participant's name, signature, and date. Loss or unauthorised access could compromise confidentiality.	Consent forms will be stored separately from the research dataset in a restricted-access location. Names and signatures will not be included in the working research dataset. Participants will be registered using participant codes in all research materials and analysis files.		
31. Will the research involve collecting, processing and/or storing any directly or indirectly identifiable PIRD (Personally Identifiable Research Data) including videos, pictures, IP address, gender, age etc and **what other Personal Research Data** (including personal or professional views) will you be collecting?	x		The study involves collecting indirectly identifiable research data, including age category, gender, cycling profile, questionnaire responses, interview responses, supportive behavioural response data such as reaction times and brake input, and researcher observation notes. Although no video or audio recordings are made, re-identification could still be possible if multiple background variables are combined in a small sample.	Only data necessary for the research questions will be collected. Background variables will be recorded in broad categories where possible. Participants will be assigned participant codes. The working dataset will be pseudonymised. Direct identifiers will not be included in the research dataset. Results will be reported in aggregated or de-identified form wherever possible.		
32. Will this research involve collecting data from the internet, social media and/or publicly available datasets which have been originally contributed by human participants		x				
33. Will your research findings be published in one or more forms in the public domain, as e.g., Masters thesis, journal publication, conference presentation or wider public dissemination?	x		Public reporting in the Master's thesis or presentations may create a risk of indirect identification if individuals are described too specifically.	No names or direct identifiers will be used in public outputs. Findings will be reported in aggregated or de-identified form. If participant comments are quoted, they will be quoted anonymously and only in a way that does not reasonably identify the participant.		
34. Will your research data be archived for re-use and/or teaching in an open, private or semi-open archive?		x				

			If YES please complete the Risk Assessment and Mitigation Plan columns below.		*Please provide the relevant reference #*	
ISSUE	**Yes**	**No**	**RISK ASSESSMENT – what risks could arise?** *Please ensure that you list ALL of the actual risks that could potentially arise – do not simply state whether you consider any such risks are important!*	**MITIGATION PLAN – what mitigating steps will you take?** *Please ensure that you summarise what actual mitigation measures you will take for each potential risk identified – do not simply state that you will e.g. comply with regulations.*	**DMP**	**ICF**
partner company collaborating in the research? Or are they one of only a handful of (expert) participants in the study?						
D: Recruiting Participants						
11. Will your participants be recruited through your own, professional, channels such as conference attendance lists, or through specific network/s such as self-help groups	x		Participants will be recruited in the testing context at the Gazelle Experience Cente. Recruitment through this project-related and professional context may create the impression that participation is expected or preferred.	Participants will be informed clearly that participation is entirely voluntary and that refusal has no negative consequences. Recruitment communication at the Gazelle Experience Center will be neutral and non-pressuring. Participants will only take part if they explicitly choose to do so after receiving the study information.		
12. Will the participants be recruited or accessed in the longer term by a (legal or customary) gatekeeper? (e.g., an adult professional working with children; a community leader or family member who has this customary role – within or outside the EU; the data producer of a long-term cohort study)	x		A gatekeeper at the Gazelle Experience Center may unintentionally influence who participates or how free individuals feel to decline participation.	The gatekeeper will only facilitate contact and access. Informed consent will be obtained directly by the researcher. Participants will be informed that participation is voluntary and independent of the gatekeeper.		
13. Will you be recruiting your participants through a crowd-sourcing service and/or involve a third party data-gathering service, such as a survey platform?		x				
14. Will you be offering any financial, or other, remuneration to participants, and might this induce or bias participation?		x				
E: Subject Matter *Research related to medical questions/health may require special attention. See also the website of the CCMO before contacting the HREC.*						
15. Will your research involve any of the following: • Medical research and/or clinical trials • Invasive sampling and/or medical imaging • Medical and *In Vitro Diagnostic Medical* Devices Research		x				
16. Will drugs, placebos, or other substances (e.g., drinks, foods, food or drink constituents, dietary supplements) be administered to the study participants? *If yes see here to determine whether medical ethical approval is required*		x				
17. Will blood or tissue samples be obtained from participants? *If yes see here to determine whether medical ethical approval is required*		x				
18. Does the study risk causing psychological stress or anxiety beyond that normally encountered by the participants in their life outside research?		x				

H: More on Informed Consent and Data Management

__NOTE:__ You can find guidance and templates for preparing your Informed Consent materials) here

Your research involves human participants as Research Subjects if you are recruiting them or actively involving or influencing, manipulating or directing them in any way in your research activities. This means you must seek informed consent and agree/ implement appropriate safeguards regardless of whether you are collecting any PIRD.

Where you are also collecting PIRD, and using Informed Consent as the legal basis for your research, you need to also make sure that your IC materials are clear on any related risks and the mitigating measures you will take – including through responsible data management.

Got a comment on this checklist or the HREC process? You can leave your comments here

IV. Signature/s

Please note that by signing this checklist list as the sole, or Responsible, researcher you are providing approval of the completeness and quality of the submission, as well as confirming alignment between GDPR, Data Management and Informed Consent requirements.

Name of Corresponding Researcher (if different from the Responsible Researcher) (print)

Luc Joël Jansen

Signature of Corresponding Researcher:

Date: 31/03/2026

Name of Responsible Researcher (print)

Stefan Persaud

Signature (or upload consent by mail) Responsible Researcher:

Date: 01/04/2026

V. Completing your HREC application

Please use the following list to check that you have provided all relevant documentation

Required:

- **Always:** This completed HREC checklist
- **Always:** A data management plan (reviewed, where necessary, by a data-steward)
- **Usually:** A complete Informed Consent form (including Participant Information) and/or Opening Statement (for online consent)

APPENDIX

APPENDIX O - DATA MANAGEMENT PLAN (USER TESTING)

Plan Overview

A Data Management Plan created using DMPonline

Title: User evaluation of a directional haptic warning system in a desktop-based simulated cycling context

Creator: Luc Jansen

Principal Investigator: Luc Jansen

Contributor: Stefan Persaud, Luc Jansen, Joost Alferink

Affiliation: Delft University of Technology

Template: TU Delft Data Management Plan template (2025)

Project abstract:

This project evaluates a directional haptic warning prototype in a controlled desktop-based simulated cycling context. The research is conducted as part of a TU Delft Master's graduation project in Industrial Design Engineering. Adult participants will be recruited as volunteers at the Gazelle Experience Center in Dieren. During the study, participants remain seated at a desk in front of a monitor and are not exposed to live traffic or real bicycle riding. They will wear a prototype helmet and use a prototype handlebar interface while watching short simulated traffic scenarios. During these scenarios, the system provides directional haptic warning cues through vibration. The study focuses on whether this interaction modality is experienced as acceptable in terms of perceived workload, usefulness, satisfaction, clarity, perceived safety, and irritation. Data collected may include questionnaire responses, interview responses, researcher observation notes, and supportive behavioural response data such as reaction time and brake input. No video or audio recordings will be made.

ID: 201437

Start date: 02-04-2026

End date: 22-04-2026

Last modified: 01-04-2026

User evaluation of a directional haptic warning system in a desktop-based simulated cycling context

0. Administrative questions

1. Provide the name of the data management support staff consulted during the preparation of this plan and the date of consultation. Please also mention if you consulted any other support staff.

The data management aspects of this project were discussed with my graduation supervisor, Stefan Persaud, and mentor, Joost Alferink. If further consultation is required, Matthijs Netten (datasteward-ide@tudelft.nl), the IDE Faculty Data Steward, may be contacted for additional guidance. No formal review by the Data Steward has taken place yet.

2. Is TU Delft the lead institution for this project?

- Yes, leading the collaboration – please provide details of the type of collaboration and the involved parties below

TU Delft is the lead institution for this Master's graduation research project. The research is conducted by a TU Delft student within the Faculty of Industrial Design Engineering and supervised by TU Delft academic staff.

The project has external advisory involvement from MODYN and takes place in the testing context of the Gazelle Experience Center in Dieren. MODYN provides expertise and feedback only. Gazelle provides the testing context and is an interested stakeholder in the broader project, but does not collect, process, or store participant-related research data. All research design, data collection, analysis, and data management are conducted under TU Delft academic responsibility.

I. Data/code description and collection or re-use

3. Provide a general description of the types of data/code you will be working with, including any re-used data/code.

Type of data/code	**File format(s)**	**How will data/code be collected/generated?** *For re-used data/code: what are the sources and terms of use?*	**Purpose of processing**	**Storage location**	**Who will have access to the data/code?**

Informed consent forms	Paper forms and scanned .pdf files	Signed by participants on paper before participation and scanned afterwards to PDF. The informed consent form is the only document containing participant names.	To obtain and document informed consent.	Paper originals stored securely in a separate physical location from the research data; scanned copies stored in a separate folder on TU Delft OneDrive	Student researcher; supervising academic staff if needed
Participant background questionnaire	Paper forms, later .xlsx	Completed by participants on paper before the test session and manually entered into Excel afterwards. The questionnaire includes broad background variables such as age category (18–29 / 30–44 / 45–59 / 60–74 / 75+), gender, cycling profile, helmet fit, and familiarity with feedback systems.	To describe the participant sample and to contextualise the research findings.	Paper forms stored securely in physical form; digital version stored on TU Delft OneDrive	Student researcher; supervising academic staff if needed
NASA-TLX questionnaire responses	Paper forms, later .xlsx	Completed by participants on paper after the test session and manually entered into Excel afterwards.	To assess perceived workload during the interaction with the prototype.	Paper forms stored securely in physical form; digital version stored on TU Delft OneDrive	Student researcher; supervising academic staff if needed
Van der Laan scale responses (pre- and post-test)	Paper forms, later .xlsx	Completed by participants on paper before and after the prototype experience and manually entered into Excel afterwards.	To assess perceived usefulness and satisfaction before and after use of the prototype.	Paper forms stored securely in physical form; digital version stored on TU Delft OneDrive	Student researcher; supervising academic staff if needed
Trial observation notes	Paper notes, later .xlsx / .docx	Recorded by the researcher on paper during the session and digitised afterwards. Notes may include interpretation correctness, missed responses, visible hesitation, and notable behaviour.	To document researcher observations during the trials and support interpretation of the test results.	Paper forms stored securely in physical form; digital version stored on TU Delft OneDrive	Student researcher; supervising academic staff if needed

Qualitative interview notes / responses	Paper notes, later .docx / .xlsx	Collected during a short semi-structured interview after the test session. Notes will be taken on paper by the researcher and digitised afterwards. No audio recordings will be made.	To explore participants' experiences regarding clarity, usefulness, satisfaction, safety, irritation, and suggestions for improvement.	Paper forms stored securely in physical form; digital version stored on TU Delft OneDrive	Student researcher; supervising academic staff if needed
Supportive behavioural response data	.csv / .xlsx	Logged digitally by the test system during the session. This may include reaction time, brake input, and brake side.	To provide supportive behavioural data alongside the questionnaire and interview data.	TU Delft OneDrive	Student researcher; supervising academic staff if needed
Excel working dataset	.xlsx	Created by manually entering paper-based questionnaire data, observation notes, and interview notes into Excel and combining them with the supportive digital system data.	To organise, clean, and prepare the dataset for analysis.	TU Delft OneDrive	Student researcher; supervising academic staff if needed
SPSS analysis files	.sav / .spv / .sps	Created by the researcher during quantitative data analysis.	To analyse questionnaire and supportive behavioural data.	TU Delft OneDrive	Student researcher; supervising academic staff if needed
Codebook / README documentation	.txt	Created by the researcher during the project to document dataset structure, variable meanings, coding, and file organisation.	To support data organisation, transparency, and later interpretation of the dataset.	TU Delft OneDrive	Student researcher; supervising academic staff if needed

II. Storage and backup during the research process

4. How much data/code storage will you require during the project lifetime?

- < 250 GB

5. Where will the data/code be stored and backed-up during the project lifetime? (Select all that apply.)

- TU Delft OneDrive

III. Data/code documentation

6. What documentation will accompany data/code? (Select all that apply.)

- Data – README file or other documentation explaining how data are organised

A README file will accompany the digital dataset to explain how the files are organised, including the questionnaires, observation notes, interview notes, supportive behavioural response data, the Excel dataset, and the SPSS analysis files

IV. Legal and ethical requirements, code of conducts

7. Does your research involve human subjects or third-party datasets collected from human participants?

If you are working with a human subject(s), you will need to obtain the HREC approval for your research project.

- Yes – please provide details in the additional information box below

Yes. This research involves adult human participants who voluntarily take part in a user evaluation of a directional haptic warning prototype. Ethical approval will be requested from the TU Delft Human Research Ethics Committee before data collection begins. All participants will provide written informed consent before participation.

8. Will you work with personal data? (This is information about an identified or identifiable natural person, either for research or project administration purposes.)

- Yes

Yes. This study involves processing limited personal data. The informed consent form contains the participant's name, signature, and date, and is the only document containing direct identifiers. All

other research materials will be coded with participant IDs only. The study also involves indirectly identifiable research data, such as age category, gender, cycling profile, questionnaire responses, interview responses, and supportive behavioural response data.

9. Will you work with any other types of confidential or classified data or code as listed below? (Select all that apply and provide additional details below.)

If you are not sure which option to select, ask your Faculty Data Steward for advice.

- No, I will not work with any other types of confidential or classified data/code

10. How will ownership of the data and intellectual property rights to the data be managed?

For projects involving commercially-sensitive research or research involving third parties, seek advice of your Faculty Contract Manager when answering this question.

This is a TU Delft Master's graduation project conducted under TU Delft academic responsibility. The research data and outputs are produced by the student researcher. MODYN provides advisory input only, and Gazelle provides the testing context at the Gazelle Experience Center in Dieren, but neither party owns or controls the participant-related research data. Access to the research data is restricted to the student researcher and, where necessary, supervising academic staff.

11. Which personal data or data from human participants do you work with? (Select all that apply.)

- Other types of personal data or other data from human participants – please provide details below
- Free text fields (for instance, in questionnaires) in which participants could unintentionally share personal data
- Proof of consent (such as signed consent materials which contain name and signature)
- Date of birth and/or age
- Gender

The study also involves indirectly identifiable research data such as age category rather than exact age (18–29, 30–44, 45–59, 60–74, 75+), gender, cycling profile information, questionnaire responses, interview responses, researcher observation notes, and supportive behavioural response data such as reaction time, brake input, and brake side. The informed consent form is the only document containing direct identifiers. All other research materials use participant IDs only.

12. Please list the categories of data subjects and their geographical location.

The participants in this research are adult volunteers recruited in the testing context at the Gazelle Experience Center in Dieren. The preferred participant group consists of cyclists aged 60 and above, although participants aged 40+ or 50+ may also be included if necessary. Participants are located in the Netherlands.

13. Will you be receiving personal data from or transferring personal data to third parties (groups of individuals or organisations)?

- No

16. What are the legal grounds for personal data processing?

- Informed consent

17. Please describe the informed consent procedure you will follow below.

Potential participants will be informed about the purpose, procedure, and expected duration of the study before deciding whether to participate. They will also be informed about what personal data and research data may be collected, how the data will be used, and how their privacy will be protected.

Participants will receive the participant information and informed consent form before the start of the session. They will have the opportunity to ask questions before signing the consent form on paper. After signing, the participant will be assigned a participant ID. This participant ID will be used on all questionnaires, notes, and analysis files.

The informed consent form is the only document containing the participant's name. All other research materials will be pseudonymised using participant IDs only. Participants will also be informed that participation is voluntary, that they may stop at any time without negative consequences, and that they may request deletion of their identifiable or linkable data until 9 April 2026.

18. Where will you store the physical/digital signed consent forms or other types of proof of consent (such as recording of verbal consent)?

The signed informed consent forms will be collected on paper. The paper originals will be stored securely in a separate physical location from the rest of the paper-based research data. They will also be scanned and stored as PDF files in a separate restricted-access folder on TU Delft OneDrive.

The consent forms will remain physically and digitally separated from the research dataset in order to prevent direct re-identification of participants.

19. Does the processing of the personal data result in a high risk to the data subjects? (Select all that apply.)

If the processing of the personal data results in a high risk to the data subjects, it is

required to perform a Data Protection Impact Assessment (DPIA). In order to determine if there is a high risk for the data subjects, please check if any of the options below that are applicable to the processing of the personal data in your research project.

If any category applies, please provide additional information in the box below. Likewise, if you collect other type of potentially sensitive data, or if you have any additional comments, include these in the box below.

If one or more options listed below apply, your project might need a DPIA. Please get in touch with the Privacy team (privacy-tud@tudelft.nl) to get advice as to whether DPIA is necessary.

- None of the above apply

23. What will happen with the personal data used in the research after the end of the research project?

- Other – please explain below
- Anonymised or aggregated data will be shared with others

The working research dataset will be pseudonymised and will use participant IDs only. Aggregated or de-identified findings may be included in the Master's thesis and related academic outputs.

The informed consent forms, which contain direct identifiers, will be stored separately from the research dataset in accordance with TU Delft research ethics requirements.

24. For how long will personal research data (including pseudonymised data) be stored?

- 10 years, in accordance with the TU Delft Research Data Framework Policy

25. How will your study participants be asked for their consent for data sharing?

- Other – please explain below (see guidance for additional options)

Participants will be informed through the informed consent form that direct identifying participant data will not be shared with external parties and that findings will only be reported in aggregated or de-identified form. The informed consent form also explains that the final Master's thesis will be published in the TU Delft Master's Thesis Repository, and that MODYN and Gazelle may only access the information included in the published thesis. Participants provide consent for participation and data processing by signing the informed consent form before the start of the session.

V. Data sharing and long term preservation

27. Apart from personal data mentioned in question 23, will any other data be publicly shared?

Please provide a list of data/code you are going to share under 'Additional Information'.

- All other non-personal data/code underlying published articles/reports/theses

Non-personal research materials may be shared as part of the Master's thesis submitted to the TU Delft Repository. These may include descriptions of the research methodology, aggregated findings, design rationale, and other non-identifiable research outputs produced during the project. Raw participant data, consent forms, questionnaires, observation sheets, interview notes, and supportive behavioural datasets will not be publicly shared because they contain personal or indirectly identifiable information.

29. How will you share research data/code, including those mentioned in question 23?
Select all that apply and provide additional details below.

- I am a Bachelor's/Master's student at TU Delft and I will share the data/code in the body and/or appendices of my thesis/report in the TU Delft Repository

My research outputs will be shared as part of my Master's graduation thesis submitted to the TU Delft Repository. The thesis will include descriptions of the research methodology, aggregated findings, and de-identified summaries of participant responses where relevant. Raw participant data, paper forms, consent forms, and any directly or indirectly identifying research materials will not be publicly shared.

30. How much of your data/code will be shared in a research data repository?

- Not applicable - No data/code will be shared in a repository

Not applicable. No separate dataset or code package will be shared in a research data repository. Research outputs will be shared through the TU Delft Repository as part of the Master's thesis only.

31. When will the data/code be shared?

- As soon as corresponding results (papers, theses, reports) are published

Research outputs will be shared through the TU Delft Repository as part of the Master's thesis. No raw participant data or separate dataset will be shared.

32. Under what licence(s) will the data/code be released?

APPENDIX

- Other – please explain below

The Master's thesis submitted to the TU Delft Repository will be shared under the standard copyright conditions applied to TU Delft theses, unless another licence is explicitly selected during thesis deposit. No separate research dataset or code package will be released under an open licence.

VI. Data management responsibilities and resources

33. If you leave TU Delft (or are unavailable), who is going to be responsible for the data/code resulting from this project?

Stefan Persaud, Chair at Delft University of Technology, Faculty of Industrial Design Engineering, with email address

34. What resources (for example financial and time) will be dedicated to data management and ensuring that data will be FAIR (Findable, Accessible, Interoperable, Re-usable)?

I will handle the data management myself using resources provided by TU Delft, including TU Delft OneDrive and standard office and analysis software such as Excel and SPSS. The dataset is expected to remain relatively small, and no additional financial resources are currently required for data management or long-term preservation beyond the resources already provided by TU Delft.

35. Which faculty do you belong to?

- Faculty of Industrial Design Engineering (IDE)

This project is conducted within the MSc Integrated Product Design programme at the Faculty of Industrial Design Engineering, TU Delft.

APPENDIX P - SHOWCASE GRADUATION PROJECT (INFOGRAPH)

3D SPATIAL HAPTICS

FEEL THE HAZARD BEFORE YOU SEE IT

Urban traffic is becoming more complex, with busy intersections, limited visibility, and significant speed differences. Especially elderly cyclists who must respond quickly in traffic situations like these are vulnerable and rely more on safety systems. At the same time, most existing warning systems rely on screens or sound, adding extra demand to senses that are already heavily used during cycling.

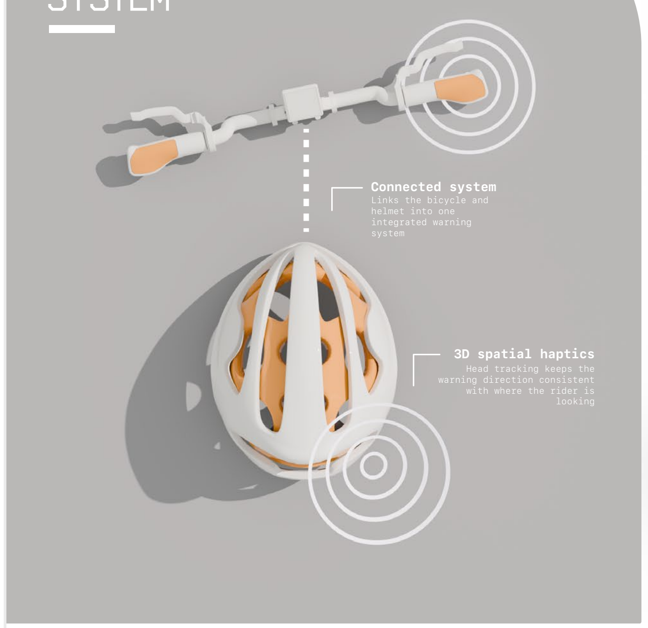
A new approach: a directional haptic warning system that translates hidden hazards into vibration cues on the body, using a **3D spatial haptic helmet** and **vibrating handles**. It creates an additional sensory layer that helps cyclists feel where danger is coming from.

Rather than overloading the cyclist with more information, this system focuses on delivering only what matters, when it matters. In this way, it acts less like a conventional alarm and more like a subtle *"sixth sense"* for cycling.

"Not a screen. Not a sound. A feeling!"

B2X READY FEEDBACK

HAPTICS SYSTEM



SAFE TESTING

Luc Joël Jansen
15/04/2026
4824490

Msc Integrated Product Design
Faculty of Industrial Design Engineering
Delft University of Technology

Supervisory team TU Delft:
S.M. Persaud Msc (Chair)
Ir. J.R. Alferink (Mentor)

Supervisor MODYN:
MA Gert-Jan van Breugel (Managing Director)

TU Delft

APPENDIX Q - INVITATION FOR THE GRADUATION PRESENTATION

NOTE ON **USE OF AI**

- **ChatGPT** was used to assist with troubleshooting Arduino and webserver code, including support in understanding and applying external libraries developed by third parties, as well as in explaining error messages during debugging. It was also used to translate, rewrite, and improve parts of the text in more correct academic English. In addition, ChatGPT was used to generate the Donald Duck image included in this report.
- **NotebookLM** was used to help reconnect statements and findings to the correct research sources during the writing process. All research papers were collected and reviewed before use, and all references were checked before inclusion.
- **Grammarly** was used for spelling checks and for further improvement of the academic writing style.

All AI-generated output was reviewed and adapted where necessary, and no results were included without verification.