PulsePath

Designing An Integrated Vibro-Tactile Navigation Assistance Interface for Electric Motor-cycles
Master´s thesis in Interaction Design and Technologies

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Cover: Photograph of a RGNT electric motorcycle.

Abstract

The use of visual feedback for navigation while motorcycling poses a significant risk as it diverts the rider's attention from the traffic situation, compromising their safety as any visual aversion longer than two seconds significantly increases the risk of accidents. This master's thesis presents the design and evaluation of a prototype for an integrated vibro-tactile navigation interface aimed at addressing this challenge.

The study involved the development of a prototype that effectively communicated directional information for navigation events such as turns and roundabouts. Since the act of motorcycling in itself can be an equally, if not more, important when choosing to travel with a motorcycle, a user-centered approach was adopted to consider the hedonic and joyful aspects of motorcycling in addition to the safety requirements. The user experience, or UX, was examined using Marc Hassenzahl's *hedonic/pragmatic model of user experience* [5] as it can encompass all aspects of motorcycling.

The prototype was evaluated with a sample of 10 participants in a real-world setting, with the objective to assess the impact on vehicle control, cognitive workload and riding experience during navigation tasks. The results showed no substantial negative effects on vehicle control, indicating the effectiveness of the vibro-tactile navigation interface in maintaining rider control while simultaneously receiving navigation guidance. Moreover, the participants reported a decrease in cognitive workload, as the vibro-tactile feedback enabled them to focus more on the riding experience rather than being distracted by visual navigation aids. The findings regarding the UX demonstrated that the integration of vibro-tactile feedback enhanced the overall hedonic aspects of motorcycling, as it allowed the riders to immerse themselves fully in the riding experience. Furthermore, the use of vibro-tactile cues contributed to a heightened sense of safety by enabling riders to maintain their visual focus on the traffic situation while still receiving reliable navigation information.

The outcomes of this research contribute to the field of motorcycle navigation interfaces and highlight the potential of vibro-tactile technology in enhancing safety and rider experience. The findings emphasize the importance of multimodal interfaces that include haptic feedback, paving the way for future advancements in the design of motorcycle navigation systems that prioritize safety, usability, and the user experience.

Keywords: User Experience, Navigation, Motorcycling, Electric Vehicles, Haptic Feedback, HCI, Transportation, User-Centered Design, Traffic Safety, Multimodal Interfaces.

Acknowledgements

Contents

1

Introduction

For the modern motorcyclist, using navigation software has become commonplace when travelling from point A to point B. In preparation or in-transit, many motorcyclists utilise their smartphones in some way [14]. However, using a smartphone in connection with motorcycling is not always easy. If the motorcyclist wants to see the screen while riding they will have to attach a mount to their motorcycle, and if they don't they will have to keep their phone in their pocket and hope that the system is online while riding. Not only is operating a smartphone while wearing riding gloves cumbersome - it is incredibly dangerous since averting visual focus from the road ahead can lead to devastating accidents [15, 20].

To eliminate the need for a smartphone, motorcycle manufacturers can build motorcycles with integrated screens. With the use of GPS, the motorcycle itself could satisfy the navigation needs of the rider. The problem with an integrated screen is that it is still a screen. While riding a motorcycle, averting ones vision from the road for longer than two seconds significantly increases the risk of accidents [20]. Adding audial navigation feedback can decrease the amount and length of screen glances, but has been found to have no significant effect on driving performance [21].

Another way to decrease the occurrence of in-transit screen glances is to use *tactility* for interpreting navigation instructions. If encoded correctly, findings suggest that utilizing vibrations to provide navigational instruction in the context of automobiles lessens the driver's cognitive load [32, 33], making it possible for them to focus on the driving task. For motorcycling, vibro-tactile navigation assistance has been researched and can be considered both feasible and positively affecting the motorcycling experience [36, 37] as it reduces the mental workload of the rider.

The research on vibro-tactile navigation feedback in relation to motorcycling has thus far only been conducted with internal combustion engine-powered motorcycles. Internal combustion engines produce vibrations that propagate through the motorcycle [34], making it difficult for the rider to distinguish between vibro-tactile navigation instructions from vibrations produced by the engine. In previous studies, this issue has been mitigated by placing the source of the navigational assistance vibrations on body parts less affected by the system vibrations [36, 37]. As electric motors generally produce less vibrations than internal combustion engines, vibro-tactile navigation assistance could possibly be successfully integrated into an electric motorcycle.

The partner for this Master's thesis - *RGNT Motorcycles* - is an electric motorcycle design and manufacturing company based in Kungsbacka, Sweden, established in 2019 [3]. At the time of writing, they produce two models available for purchase, 'The No.1 Scrambler SE' and 'The No.1 Classic SE', the latter shown in 2.1. Both models are fully electrically powered A1 motorcycles with integrated touch-screen interfaces, retailing for around 15 000€.

Figure 1.1: Profile view of a RGNT *No. 1 Classic SE* electric motorcycle. Source: RGNT Motorcycles [3]

In this thesis, the design process and evaluation of an integrated vibro-tactile navigation feedback system for electric motorcycles will be described. Further, important aspects to consider when designing vibro-tactile navigation instructions will be presented as a help in further development. The thesis will emphasize on the user experience in relation to the hedonic/pragmatic user experience model by Marc Hassenzahl [5].

The vibro-tactile navigation feedback system, *PulsePath*, presented in this thesis consists of a smartphone application connected to a micro-controller that powers two vibration motors integrated into the handlebars of an electric motorcycle. When approaching a turn or a roundabout, the vibration motors communicate the proximity and direction to the rider by sending different vibration signals relating to the suggested action. The system was evaluated in a real-world setting where n=10 participants rode the motorcycle for two trips - one with visual feedback provided from the smartphone and one with visual feedback in combination with the vibro-tactile feedback. Braking data from the different trips was collected to measure the system's impact on vehicle control, while the amount of navigation errors and the NASA-TLX questionnaire [82] was utilized to measure the effectiveness and

workload respectively. To evaluate the user experience between the two modes of navigation, the AttrakDiff3 questionnaire was used in combination with a qualitative interview.

The evaluation showed a small change of -0.4% in the percentage of hard braking ($p < 0.001$) and a small but statistically insignificant change in the amount of (average) navigation errors from 1 to 0.6 ($p = 0.161$) in favor of PulsePath. In terms of workload, statistically significant changes was shown overall in favor of PulsePath ($t(9)$ = -2.975, $p = 0.021$), with *frustration* being the most significant aspect when examining individual subscales ($t(9)$ = -4.422, $p = 0.002$). The user experience was found to be improved in the evaluation. Statistically significant changes were found in all four qualities examined with the AttrakDiff3 questionnaire ($p < 0.001$). When asked about how using PulsePath affected the motorcycling experience, all participants answered positively. The vibro-tactile feedback helped them direct their attention to the surroundings, making navigating in traffic feel safer and allowing them to focus more on the act of motorcycling.

1.1 Aim

The aim of the Master's thesis is to describe the design process and evaluation of an integrated vibro-tactile navigation assistance interface and it's impact on the user experience of riding an electric motorcycle. Furthermore guidelines for how to encode navigational instructions into the vibrotactile domain will be examined and presented.

1.2 Limitations

The Master's thesis project will focus on designing and creating a *prototype* to aid in answering the research questions presented below. Implementation for production will not be considered.

The Master's thesis will also focus on motorcycling as a *leisure activity* and for *commuting* in an urban environment, meaning that motorcycling for professional uses - for example food delivery or taxi driving - will not be taken into consideration. Also, motorcycling as a sport (i.e. track racing or enduro racing) and motorcycling in extreme terrain will not be considered.

1.3 Research questions

Given the context of operating an electric motorcycle in an urban environment with the prototype created in this project (i.e. PulsePath), the purpose of this Master's thesis is to answer the following research questions:

RQ1: What aspects should be considered when designing integrated vibro-tactile navigation assistance?

RQ2: How does using the vibro-tactile navigation assistance feedback provided by PulsePath affect the riding experience?

2
Background

In this chapter RGNT and their product is presented, as well as a brief description of the context in which the master's thesis resides - i.e. the world of motorcycling.

2.1 RGNT

Figure 2.1: Profile view of a RGNT *No. 1 Classic SE* electric motorcycle. Source: RGNT Motorcycles [3]

RGNT is a electric motorcycle design and manufacturing company based in Kungsbacka, Sweden, established in 2019. They produce two models available for purchase, 'The No.1 Scrambler SE' and 'The No.1 Classic SE' (shown in 2.1). Both are fully electrical powered two-wheelers (PTW) positioned to target the premium segment of the market. The motorcycles are equipped with a 9.5kWh battery allowing them a range of around 148km and a top speed of 120km/h, and are used primarily for commuting and leisure according to the company. It takes 3h to charge the batteries from 20-80%. Each motorcycle is hand-built to order with high-quality materials and retails for around 15 000€, and are available in Europe exclusively at the time of writing. The company offers a twofold value proposition to riders, incorporating

both a visually appealing "classic look" in the bikes' design and a comprehensive digital ecosystem integrated into the motorcycle. A 7-inch LCD display mounted on the handlebars of each motorcycle provides riders with access to the digital ecosystem. To interact with the software the driver can either use the touch screen functionality of the screen or a joystick mounted on the right handle. To aid in safe driving, the touch functionality is not enabled when the motorcycle is in motion.

Currently - when in transit - the screen provides information to the driver of traveling speed, battery levels and momentary power drain. At the time of writing, RGNT is in the works of development and launch of trip-planning and turn-by-turn navigational tools that will be deployed in the near future. As part of this endeavour, RGNT wants to explore what *"the future of navigational assistance"* could entail in the context of motorcycling, which is what this thesis aims to explore.

2.2 Electric motorcycles

In this paper "electric motorcycles", "e-motorcycles" or "e-PTWs" will be used to describe 2- or 3- wheeled road vehicles which are propelled solely by an electrical motor. Electric bicycles, where the electric motor assist the user's pedalling are thus outside what is considered e-motorcycles. Electrical motorcycles are equipped with a rechargeable battery - most often lithium-ion batteries [6]. In Sweden motorcycles are divided into 3 categories, which requires different licenses in order to legally drive them on the road [7]: light motorcycles with a maximum net output of 11 kW, medium sized motorcycles with a maximum net output of 35kW and heavy motorcycles with output above 35 kW. Both RGNT motorcycles are in the *light* class.

The global market for electric motorcycles is projected to have an annual compound growth rate of 10.2%, reaching a market size of 109.5 billion U.S. Dollars in 2030 from 55.4 billion USD in 2023 [1]. In five of the largest European markets (France, Germany, Italy, Spain and the United Kingdom), e-PTWs can be considered a niche market with only 4.6% of new PTW registrations being for e-PTWs in 2022 [8]. In a 2021 survey focusing on the European market by Will et al., [9] participants mentioned the *riding experience*, specifically the simplicity, of an e-PTW as the most common reason for choosing it over an ICE-powered PTW. Personal interest in, or professional contact with, novel technology was also mentioned as an important reason for buying an e-PTW. High price, limited driving range and lackluster charging infrastructure were the most prominent reasons against buying an e-PTW [9].

Range anxiety refers to the psychological anxiety a person experiences in response to the limited range of an electric vehicle [30]. In contrast to their combustion-powered counterparts, electric vehicles in general have shorter range and longer refill times in regards to their power source (e.g. electricity or petrol) which can create a fear of being stranded without access to power [30].

2.3 The act of motorcycling

Motorcycling sets itself apart from other modes of transportation in regards to user motivation. The destination is not necessarily the main goal for the rider, but rather the act of using their motorcycle [10]. The reason for riding can simply be to "go for a ride" with the intention to express themselves through riding the motorcycle [10].

When motorcyclists participating in a 2021 study were asked for motivations to why they ride their motorcycle, their primary reason was to experience *contact with a natural environment*(appreciation of beauty) [27]. Following that, *the rush*(adrenaline, excitement), *friendship*, and *fulfilment* were the most common motivations [27]. Although all of these motivations are important to take into consideration when creating a product that relates to the *hedonic* aspects of the motorcycling experience, there is one central insight that allows us to understand the riders - the journey is as important as the destination, if not more [10, 27, 28]. As a lot of the previous research is within the context of *motorcycle tourism*, it would need to be established that the same motivations are present for e-motorcycles with shorter range and different vehicle characteristics than their combustion-powered counterparts.

A common conception of motorcyclists is that they are risk-seeking individuals who seek the thrill of danger. Although there is evidence that suggests that PTW drivers have higher risk-seeking behaviour, they are also aware of the risks they expose themselves to [18]. Furthermore, when riding, they do not perceive the most dangerous or complicated maneuvers as the most enjoyable part of the experience [11]. Rather, motorcyclists seek driving situations which they consider cognitively demanding enough to demand attention without a high risk of a crash [11]. The psychological goal is argued to be to reach a state of *flow*, where the riders ability is challenged in a way which demands the drivers full attention without exposing themselves to an unnecessary risk of injury [11].

2.3.1 Motorcycling and in-transit HCI

Drivers, regardless of vehicle type, have come to expect dynamic navigational guidance and support to be provided whilst in transit [12]. When participating in a 2015 study about the usage of navigation assistance systems, above 50% of participating drivers reported to use a navigation system for more than 1/4 of their trips, especially so when destination was unfamiliar [13]. In market research by Bosch Softtec, motorcyclists stated that they want their bikes to provide connection and functionally the same way their smartphones do, navigation assistance being the most sought after feature [14]. In the same study, they also found that nearly 90% of the participants used their smartphone for some aspects of their travel, and 44% used their smartphone mid-transit [14].

Travelling from destination A to B is typically an activity which is considered *a means to an end* [2]. Trip planning under that condition then becomes a utility

maximisation problem where the agent optimizes for factors such as *arrival time*, *travel time*, and *cost* [2]. Under such circumstances, users expect travel information services to aid them to reach that goal [2]. Since motorcyclists value 'the journey in itself' as stated above in section **2.3**, a navigational assistance system for this demographic should emphasize the journey itself as much as reaching the destination.

Operating a motorcycle in traffic is inherently dangerous as losing control of the vehicle can lead to devastating, even fatal, accidents. Frequent use of smartphones for texting and/or searching for information while riding a motorcycle is strongly associated with an increased risk of accidents [15]. While operating any vehicle, even the simplest interactions with technology like listening to music or hands-free telephone conversations can impair the driver's performance [16]. Conversely, trying to interact with technology while in motion impairs the user's ability to interact with the technology in question [17]. Although this research was conducted in the context of operating automobiles [16] and walking while operating a smartphone [17], it is reasonable to assume that these insights generalize to motorcycle driving as well [18]. Because interaction with technology impairs the driver's ability to operate their vehicle and vice versa, interfaces intended to be used whilst operating a motorcycle must be easy to operate and understand while not distracting to minimize the risk of accidents.

Visual distraction has previously been defined as "any glance that competes with activities necessary for safe driving" [19]. When drivers avert their focus from the road ahead for longer than 2 seconds the risk of crashing increases significantly [20]. Ergo, looking in a rear view mirror or other glances that assess the driver's environment are not considered visual distractions [20], but looking at gauges or screen-based interfaces impair the driver's ability to operate the vehicle safely [20]. A study by Jensen, Skov and Thiruravichandran [21] found that the addition of auditory output to a visual navigation assistance interface reduced the amount of glances, but had no significant effects on driving performance. They suggest that the audio-visual interface heightens the driver's cognitive load to a point where the distraction is similar to that of a exclusively visual interface [21]. Providing instructions to the driver that do not demand visual attention could decrease the risk of accidents as they can keep focus on their surroundings.

From an experiential standpoint, Leshed et al. argues that the use of mid-transit navigational instructions transforms the experience for the driver. Instead of interpreting and engaging with their surroundings and environment, the user primarily interacts and understands the world through the virtual abstraction that the system provides [12]. This causes a loss of connection with the real world that can be described as a *detachment* and is argued to inhibit the driver's relationship with the real world and leaves them indifferent towards it [12]. However, Brown and Laurier [29] argue that the interaction between navigation assistance and driver is more complex, and that the model of the "docile driver" who blindly follows directions is incorrect. They mean that the instructions given by the GPS are more like puzzle pieces that the driver interprets and connects to their surroundings [29]. This entails

consciously interpreting the GPS suggestions and even abandoning the use of the GPS when the driver feels that the instructions are flawed [29]. The notion that the driver interprets the GPS instructions imply that the level of abstraction between GPS instructions and the real-world surroundings can be quite high, while still rendering the navigation assistance useful to the driver. A higher level of abstraction might also nudge the driver to lift their gaze and focus on their surrounding environment, making the driving experience richer. Within the context of this project, it then becomes of interest to explore if and how abstraction can be leveraged to amplify the driving experience through the development of an artifact.

As the the intended context use of the interface designed in this project is driving in traffic, it's of great importance that the prototype is safe to use as it is a safety critical situation. Minimizing visual distraction, cognitive load and other factors that can impair driving performance were essential parts considered during ideation and development of the prototype.

3

Related Work

In this chapter, previous research in vibro-tactile interfaces and its application in automotive and motorcycling contexts is presented. Further, the theories behind the different design- and research methods used in the project are presented.

3.1 Vibro-tactile displays and human factors

To be able to properly design a system that utilises vibrations as an information channel, the ability to perceive and understand vibrations need to be understood. This understanding is essential in developing a system that considers human sensitivity and comprehension of vibrations as a means of communication.

Humans´ ability to perceive and interpret vibrations is an extensively studied field within psychology [41]. The human skin consists of mechanoreceptors that react to tactile stimuli that is then converted to neural signals [40]. This tactile neurophysiological system is what enables humans to be able to distinguish and sense surfaces as well as perceive vibrations. The mechanoreceptors produce information with factors such as spatiality and temporal properties of the incoming stimulus [40]. This allows us to determine where on the body a vibration is occurring - i.e. on the left side of the torso or in the right hand. Moreover, it enables us to distinguish different characteristics of vibrations, like amplitude (pulse height) and frequency (hertz/pulse width). Empirical studies has concluded that a 20-30% difference in intensity, a combination of the vibration's amplitude and frequency, is needed to reliably discriminate between signal types in practical applications [41]. These receptors have a high temporal acuity, and in in a lab setting it is possible for users do differentiate signals with 5 ms spacing in between [41]. In practice this means that vibrations can be pulsed to encode information into the tactile domain, and that rhythm as a characteristic can be used in signal design.

The *masking effect* occurs when the perception of one stimulus is affected by the presence of another stimuli in the same domain [42]. For vibrotactile stimuli this masking occurs most prominently when another vibration with higher amplitude is present, or one with the same frequency occurs simultaneously - but any type of simultaneous vibration occurring as the stimuli of interest will affect this perception to some degree. A masking stimuli can make it difficult or impossible to discriminate and decode the information of interest from noise or other vibrations in a haptic interface. On motorcycles vibrational noise is generated from the engine, as well as

from the contact between the road and the wheels.

3.1.1   Cognitive demand and the Multiple resource model

The *multiple resource model* proposed by Wickens [43] states that different structures of cognitive resources are engaged to process different types of mental tasks. For instance, linguistic activities demands a different pool of mental resources from those required for spatial information processing - which gives most people the ability to walk and talk at the same time. This means that some tasks can be processed simultaneously, or time-shared, given that the needed resources does not overlap - with the caveat that if one sense is overloaded, processing and execution for other resource pools will degrade as well. In turn, this entails that information and multitask handling can be divided onto multiple senses to lower the cognitive workload of the user. In Wickens originally proposed model, only the visual and auditory modalities were considered as channels of inputs to the user, but there are empirical evidence to support the idea that the tactile domain could be considered a distinctly different one [44].

In the context of motorcycling, the visual domain is heavily occupied with scanning the road and to look out for potential dangers. Navigational assistance is often introduced in the visual domain, in the form of an animated map and directional instructions in the form of symbols and text. Through the lens of Wickens resource model it can be argued that such a solution will affect the processing of both tasks and degrade the task completion quality as they share the same resources. Furthermore, as the tasks can't be time-shared the driver either has to focus their vision on the road or on the map. In effect this leads to an increased risk to misjudge or miss a potential danger, and potentially the risk of an accident. If the navigation instructions instead are placed in a domain other than the visual, these tasks can potentially be executed in parallel to each other, maximizing the safety of the driver.

3.2   Vibro-tactile feedback for in-transit navigation

The use of vibrations to indicate and communicate navigational instructions has previously been explored in the contexts of both automobiles and motorcycles. In a study by Van Erp and Van Veen [32], vibration motors (motors that produce vibrations) were placed in the driver's seat of an automobile to produce vibro-tactile feedback in the left and right thigh of the driver. The vibration motors would instruct the user to take a left or right turn through activation of the motors on the corresponding side. From this study, they concluded that when multimodal information - both visual and vibro-tactile feedback - was provided to the user while driving, the user's cognitive load and reaction time decreased, ultimately freeing up cognitive resources to focus on the immediate traffic situation. Similarly, wristbands producing indicative vibrations worn by the driver were successfully employed in a 2020 study by Zhu, Liu and Zhu [33]. If the instructions are correctly encoded there

is strong evidence that the use of vibro-tactile feedback for navigation and encoding maneuver instructions into vibro-tactile stimulation is feasible [35] and has a positive affect on the driving experience.

Vibro-tactile feedback has also been utilized to communicate directions to motorcyclists. One central issue when communicating through vibrations in the context of a combustion-powered motorcycle is the vibrational noise produced by the engine that propagates and affects the whole vehicle, including the handlebars [34]. This vibrational noise caused by the engine results in difficulties for the rider to separate information communicated by the vibration motors from system vibrations. One solution to this issue is to generate vibrations at a frequency that is distinctly different from the engine noise [34]. A secondary approach is to transmit the vibrations to parts of the body less affected by the noise. *Haptimoto* [36] is a concept where vibrations are transmitted to the motorcyclist through a vest that is worn whilst driving, with vibration motors placed on the back of the shoulders and one in the center of the back. Another similar concept is *MOVING* [37], a kidney belt equipped with vibration motors that provide turn-by-turn instructions for the rider. Although both concepts successfully provided navigational instructions to the users a clear drawback of both, if creating a commercial product is a goal, are that these systems are not embedded into the motorcycle but rather peripheral devices [34], lowering the acceptability of the product. In an electric motorcycle, haptic feedback could be integrated in the handlebars since the electric motor produces considerably less vibration than a combustion-powered motorcycle. The haptic noise produced from the motorcycle's contact with the road could possibly interfere and hinder the driver from discerning the signals - which is a part of what is explored int this thesis.

3.2.1 Encoding navigation instructions into vibro-tactile sensation

In previous research, the manner of how the vibro-tactile maneuver instructions are communicated to the driver have similar characteristics. In both *MOVING* [37] and *Haptimoto* [36] the *intensity* of the feedback progressively increases to indicate when an action needs to be taken by the driver. This feedback can be divided into 4 levels of increasing intensity as the maneuver is approached [38], which is utilized to guide the user to the correct action and communicate the following:

- **Far** - A maneuver will need to be performed.
- **Near** - The user is closer to the maneuver and need to act soon.
- **Immediate** - The maneuver must be performed very soon.
- **Act now** (*optional*) - The maneuver is to be performed now.

Haptimoto [36] uses the design guidelines provided by United States' Department of Transportation [39]. These guidelines prescribe how far ahead an auditory instruction should be provided before a maneuver need to be executed, which is assumed to be transferable to haptic signals as well. The *lead distance* can be calculated with the following equation 3.1, where speed is in *km/h* and lead distance is in *meters*:

$$Lead\ distance(X) = speed * 1.1973 + 21.307 \tag{3.1}$$

Haptimoto [36] uses the lead distance to evaluate when to send the different levels of signal strength. *Low* intensity is sent at 4X (Far), *mid* intensity at 2X (Near) and *high* intensity at 1X (Immediate) of the lead distance.

Communicating to the driver ahead of time that a maneuver needs to be performed allows them to plan their driving and adjust the placement and speed of their vehicle accordingly. The increase of intensity encodes a temporal variable that informs the user when this action needs to be taken. There are multiple ways to convey an increase of intensity through vibrations [35]:

- **Repetitions** - The number of pulses per signal.
- **Pulse length** - Duration of each pulse within the signals.
- **Pulse strength** - The power of the vibrations produced by the motors.

Intensity variables can be altered in a combination to further increase the effect [35], for example increasing both pulse length and amount of repetitions. Asif et al. [35] concluded that combining an increase of repetitions with a fixed pulse length, resulting in an increase in duration for the total signal, produced the least perception errors and best result for communication of maneuver actions. However, Asif et al. [35] did not consider increasing the pulse length but rather shortening it by increasing the repetitions within a fixed total signal length.

3.3 Interface design for driving

Android Auto is a smartphone and automobile application developed by Google - with over a billion downloads [55] - that allows the user to access other applications and functionalities in a way that corresponds to the context of driving [56]. To assist designers and developers of automotive user interfaces, Google has declared principles for both interaction and graphic design that prioritise driver safety, called the *Design for Driving foundations* [57].

Although the *Design for Driving foundations* mostly relate to screen-and-audio interfaces in automobiles, the importance of minimizing the occurrence and length of screen glances is central [57]. This repeats what was stated in section **2.3.1**, indicating that designing a vibro-tactile navigation interface is a valid endeavour.

4

Methodology

In the following chapter, the theories behind the different design- and research methods used in the project are presented as well as how they relate to the project. The frameworks presented in this chapter was used to understand the activity of motorcycling, to create a complete and rigorous design process, and to evaluate the final concept through established constructs.

4.1 The hedonic/pragmatic model of user experience

As described in section **2.3**, the reason for motorcycling is not only a functional one where the goal is to reach the destination - but also consists of pleasurable, joyful and social intrinsic motivation of the activity in itself. To understand and produce an experience which catches and enables these motivations a framework that considers both functional and experiential aspects are needed. To be more precise, a framework which ensures that the user can reach their destination and have fun while doing so.

To describe user experience with interactive products, the *hedonic/pragmatic model* can be used [4]. The model assumes that users perceive interactive products in two dimensions simultaneously - the *pragmatic* and the *hedonic* [4]. The *pragmatic* dimension of a product is the perceived ability to meet the user's "do-goals" - i.e. pragmatic goals like "make a telephone call" or "browse the internet", whereas the *hedonic* dimension is more personal and refers to the product's perceived ability to meet the user's "be-goals" - for example "being perceived as competent" or "being part of a community" [4]. Within the context of e-motorcycling, a "do-goal" could be "get from point A to point B" whilst a "be-goal" could be "being free and in motion".

The model has been utilized as a framework in previous transportation research as a way to understand users and create HMI artifacts that users have acceptance towards [45]. As mentioned previously (section **2.3**), the hedonic aspects of the motorcycling experience are important, but they need the pragmatic aspects to be fulfilled in order to be realised. Therefore, we argue that analysing the UX of e-motorcycling with navigation assistance with the hedonic/pragmatic model is an acceptible way to explore the field.

4.2 Research through design

Research through design is a term for when the design process, and the resulting artefact or artefacts, serves as the basis for exploratory and generative research. In the words of Zimmerman et al, utilising a "research through design" approach in HCI is when "designers produce novel integrations of HCI research in an attempt to make the *right* thing: a product that transforms the world from its current state to a preferred state." [52]. When using a "research through design" approach, the intent of the design process is not to create a commercially successful artefact but rather to produce knowledge for the research and practice communities [52].

In the paper *Research through design as a method for interaction design in HCI* [52], Zimmerman et al present a model for design research within HCI that allow design researchers, research engineers and behavioural science researchers to collaborate on equal footing. According to Zimmerman et al, the model and the method provides five main benefits [52]. First, they state that research through design provides the HCI research community an opportunity to work with wicked problems in a way that other research methods would not [52]. Second, that the method provides an opportunity to discover usage for new technology to research engineers and gaps in behaviour theory to behavioral scientists [52]. Third, they argue that the process and results of research through design bridges the gap between the HCI research and the HCI practice community, potentially increasing the likelihood that the insights gained in research influence products in the world [52]. Fourth, the method allows for interaction designers to contribute to research by use of their skill - reframing problems through a process of trying to create the *right* thing [52]. The fifth benefit the model and method provides, according to Zimmerman et al, is that it motivates the HCI research community to discuss preferred states and reflect on the role research has in the world [52].

As this Master's thesis will use the design process to explore, we would argue that a *research through design* approach is well motivated. The approach has also been used in previous research of transportation and HCI [54].

4.3 Wicked problems

Wicked problems - a term from social science [46] that has been adopted by interaction design field [47] - describes a type of problem that are 'vague' in nature. The term has been generalized to apply to problems outside the scope of policy planning by J. Conklin [48], who states that problems that are 'wicked' in nature have the following characteristics:

1. Wicked problems can only be comprehended once a solution has been formulated.
2. There is no defined endpoint for solving wicked problems.
3. There is no correct or incorrect answer to wicked problems.

4. Each wicked problem is singular and original.
5. Finding a solution to a wicked problem is a one-time opportunity.
6. Wicked problems do not have pre-existing alternatives.

There is no singular nor definite solution to how a vibro-tactile navigational interface for an e-motorcycle should be designed. Thus, viewing it through the lens of 'wicked problems' makes it possible to adapt the design thinking method and address the research question utilising the "research through design" framework [47].

4.4 User-centered design

User-centered design(UCD) is a design philosophy pioneered by Don Norman [51] which mandates that end-users should be involved into the development stage of a design. This is to ensure that *the correct problem* is the one that is being addressed and that the resulting solution meets human needs and capabilities [51]. When approaching a HCI problem, it's not always certain that the initially proposed problem is the actual issue. Faced with a problem, designers should take one step back and examine and understand the "real" issue: the *needs* and *wants* of the users that made them want to solve the problem in the first place. Once that is established useful and good products can be created [51].

How UCD is applied and how involved the end user has to be into the design process can vary: from collecting data through interviews or observations forming the basis of a needs and requirements gathering - to actively being part of the *solve* phase as active participants in the design and ideation. What is important is that end-users are involved.

Studies within the realm of automotive and transportation have employed the principles of UCD to conceptualize and realize solutions that align with the needs and desires of their intended users [45, 50]. As this Master's thesis project will be exploring a novel navigation assistance interface and how it might be used, applying a UCD philosophy to ensure that resulting artifact is anchored in user needs and wants is essential.

4.5 Design thinking

Design thinking is a *systematic, collaborative and iterative approach for identifying and solving problems*, commonly used within new product development and innovation [49]. Design thinking has historically been successful where the problem is not well-defined, as the process puts emphasis on understanding and exploring the user and usage situation at hand [49]. As RGNT motorcycles had no native navigation assistance interface at the time of writing, and the problem statement was initially not well-defined, the design thinking approach was utilised for the project. The process has previously been used for artifact research in the field of transportation

and HCI [50].

In general, design thinking as a problem-solving approach consists of two major phases: identifying problems and solving them. The exact tools and methods used in each phase varies between projects - the ones used in this Master's thesis project are described below in sections **4.6**, **4.7**, **4.8**, **4.9**, **4.10**, **4.7**, **4.11.3**, **4.11.4** and **4.11.5**.
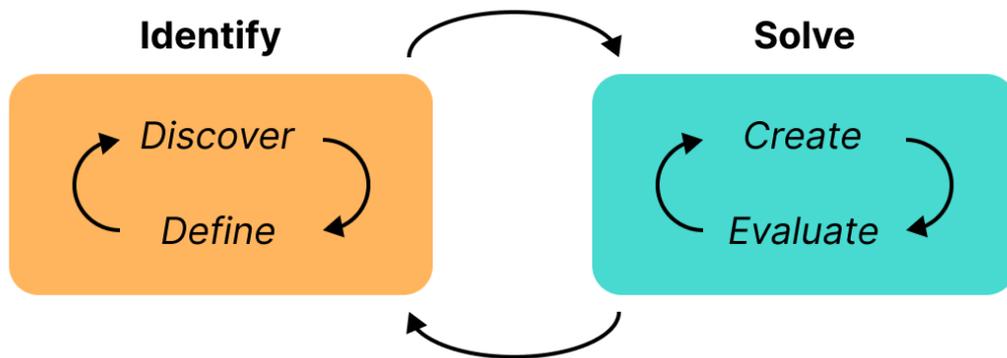
Figure 4.1: An illustration of the inter-changing phases and modes of the *design thinking* approach.

4.5.1 The *identify* phase

As the name suggests, the core purpose of the *identify* phase is to gain an understanding of the context wherein the problem at hand exists. The exploratory part of this phase is called *discover* mode, as the designer, or rather problem-solver, aims to discover problems and empathize with the user group. This can be done in a multitude of ways, commonly through qualitative interviews, observations, simulation exercises and literature reviews [49]. *Discover*-mode transitions into *define*-mode, the purpose of which being to distill and frame insights from the previous mode into well-defined problems to solve [49]. Typically, the problems are framed as problem statements which include the user type, the identified need or problem and why it needs solving [49].

4.5.2 The *solve* phase

With insights regarding the use case and a well-defined problem, a project utilizing the *design thinking* approach moves into the *solve* phase - the purpose of which is to solve the identified problems. To start, the problem-solvers act in what is called *create* mode, where they ideate and prototype to come up with various solutions through different techniques and methods. The "final" part of the design thinking process is called *evaluate mode* in which the problem-solvers test their solutions, typically with the target user group as participants. The insights from testing and evaluating different solutions can, and should, then be used in further iteration as

the problem-solvers go into any of the previous modes of the process [49]. Ultimately, the goal of the design thinking process is to move into full development of the product and/or service [49]. However, the amount of iterations between modes and phases are typically unknown at the initiation of the process [49].

4.6   Literature review

To understand the domain of motorcycling and its relation to navigation assistance, a literature review was conducted in the *identify* phase (subsection **4.5.1**) of the Master's thesis project. As neither of the authors of this thesis had much relation to motorcycling initially, this was deemed a relevant approach to gain basic knowledge of the domain.

A literature review is a systematic approach for analysing and summarizing literature on a given subject [59]. There are many different ways to conduct literature reviews and to organize the sources - for this project a *thematic* approach was chosen over a *chronological,* as the history of motorcycling was considered less important than the act of motorcycling and the people who engage in it.

4.7   Semi-structured interviews

In this project, semi-structured interviews were chosen as a method for understanding the realm of e-motorcycling and the people that engage in the activity. In relation to the *design thinking* approach (section **4.5**), the method was used in the *identify* phase (subsection **4.5.1**) to empathize with the intended user group.

The semi-structured interview is a qualitative data collection method which enables *empathizing* with the target group [60]. The interview is structured by a set of carefully *prepared questions* that addresses specific research questions or constructs of interest related to the area of research. These questions allow the interviewer guide the user to talk about and describe experiences of relevance to the research and addressing variables of interest. *Probing* the user through the use of follow-up questions allows the interviewer to understand the complexity and nuances with the topic. This openness of content can help the researcher find previously unknown domains of interest within the research area, not covered by previous research or considered during study design. The probing also allows the interviewed to explain or describe topics in a manner that reflects their lived experiences truthfully. Previous research in the automotive field utilized semi-structured interviews as a means to gather user data and gain empathy [50, 61] as well as evaluating results [62, 63]. As we aimed to understand e-motorcyclists and their relation to navigation assistance, a not particularly strictly defined realm, using semi-structured interviews might have allowed for more exploration than a more rigid approach (e.g. surveys) would.

When conducting a semi-structured interview, the questions should move from open

and broad in scope to more in-depth and theory focused towards the end. This allows the interviewer to catch and discover the subjects lived experience and study. Once this lived experience is established the interviewer can tie in and related theory driven questions to what the subject has previously said, which minimizes the amount the questions lead the participant. The semi-structured interview can be divided into three segments [60]:

- **Opening** - Establish purpose of study and trust with the participant. Ask open-ended question and probe for *clarification* in the direction which anchors the narrative in your research question.
- **Middle segment** - Higher specified in questions asked. Loop back to answers that has been given previously and probe for *meaning* from what the participant has said.
- **Closing** - Offer participants to explore their narrative in relationship to theory. Ask for further clarification and explore contradictions. Wrap up and thank the participant.

Mediating objects and artifacts can be utilized to aid the participant with building their narrative. Such tools can help the participant remember and surface ideas that might not be immediately available in their consciousness [60]. *Tools* can be both photographs or items, but also pen and paper which the participant is asked to map and sketch parts of their experience with.

4.8 Affinity diagramming

To help define the problem and analyze the findings from the semi-structured interviews (section **4.7**), affinity diagramming was chosen as the method used in the latter part of the *identify* phase (section **4.5.1**) of the project.
Affinity diagramming, or *the KJ method*, is a method used for externalizing, organizing and understanding large amounts of qualitative data, originally stemming from anthropology and social sciences but today commonly used in HCI research [68, 69] and in the field of transportation-and-HCI [63, 64]. Affinity diagramming can be used in both the *identify* and *solve* phase of a *design thinking* process(section **4.5**), as both user research and evaluation can yield considerable amounts of qualitative data [49]. Application of the method is composed of four steps: *label making*, *label grouping*, *chart-making* and *written or verbal explanation* [68].

The first part of the process, *label making*, consists of the researchers making notes of the contents from a body of data (e.g. interview recordings, transcripts, videos) on sticky notes where each note includes only one insight or concept [68]. Affinity notes usually include handwritten text, but drawings and annotations are also common [68]. The second part, *label grouping*, involves shuffling the notes and one by one putting them on a wall or whiteboard [68]. If the researchers feel that a note relates to a note on the wall, the notes are grouped together [68]. After all notes have been placed on the wall the researchers assign titles to the groups of notes as they try

to identify key concepts recognized in the data [68]. Third, *chart-making* consists of creating a sketch in which the relation between each key concept is explained as cause-and-effect, order of occurrence, interdependence, connection or contradictions are mapped out [68]. Lastly, the insights gained from the process are explained as the researchers reduce the complexity of the data to a more manageable form, e.g. a user needs specification or a collection of problem statements [68].

In the project, affinity diagramming was used to organize the data gathered during the semi-structured interviews(4.2) as the method is useful in open-ended, exploratory research, and the insights from the method were used to define the scope of the project. Another approach could be to use *thematic analysis* [70], a more rigorous but unfortunately more time-consuming method of qualitative data analysis.

4.9   Triangulation

Triangulation refers to the convergence of various techniques aimed at investigating a common research question, with the goal of confirming evidence from multiple perspectives [71]. This strengthens the conclusions and insights found if the different approaches corroborates each other, or allows the designer to uncover possible inaccuracies in their findings.

Triangulation was used in the final stages of the *identify* phase (section **4.5.1**) to define the problem.

4.10   Prototyping

Prototyping is one of the key components of the *design thinking* philosophy [49], where the theories and concepts found in the *identify*-phase (**4.5.1**) are manifested through the creation of artefacts. Prototypes can differ in fidelity, i.e. how close to the end product they are, and what aspects of the design theory they are intended to communicate. These prototypes can then be used as a communication tool to explain ideas among the designer, to participants, and as a manifestation that embodies the conclusions of the conducted research.

In the project, prototyping was used not only to create an artefact for evaluating the idea of integrated vibro-tactical navigation assistance feedback in an electric motorcycle but as a method for *ideation*. In the article *The Anatomy of Prototypes* Lim et al. [74] presents the idea of prototypes as filters. They argue that prototypes can be used to explore different dimensions of a design space to better understand how aspects of the design affects the functionality and experience for the user. Furthermore, the prototype loop where we go from ideation to implementation allows the designer to discover ambiguities in the concept that needs to be defined - aspects that were not considered during ideation [74]. This in turn refines the concept and pushes it further towards a fully formed concept. Similarily, P. Dahlstedt describes the interplay of between idea and manifestation in a creative process [75]. Where

the discrepancy between the concept and prototype can be viewed as a room for re-conceptualization - or ideation if you will. The tools and material used to manifest the idea limits the concept - but simultaneously they guide further iterations as the designer learns to understand the design vectors available for the specific tool or material [75].

4.11   Evaluation

To guide the development process of a product and assess it's effectiveness empirical test with users from the target group should be conducted during the design process [76]. Evaluation with real users ensures that design decisions are not arbitrarily chosen - but rather anchored in the real world needs and wants. The test can either be designed with the goal to discover problems in the design (*formative*) or evaluate how the designed accomplished the goal initially set out to solve (*summative*) [76].

4.11.1   Formative evaluation

To discover concrete problems and issues with an ideated solution formative tests can be conducted to highlight these [76]. Formative tests should include a fairly small amount of participants and focus on a qualitative investigation. Where the focus should be on the discovery of problems, frequency of the problems and the impact it has on the usability [76]. To leverage this approach to the fullest the test plan should test multiple iterations and variations of the concept, as well as varying the participants between iterations [76].

Informal interaction between observer and participant is essential - discussion on characteristics of the problems and how they can be solved enables the understand the root of the issues and to later ideate on concrete ideas to resolve them [76].

4.11.2   Summative evaluation

Once a concept is fully realized it should be evaluated to test whether it achieves and fulfills the issues it aims to solve [76]. This can be done either by assessing quantitative objective performance or to compare performance metrics to another similar product [76]. The first step is define quantitative objectives that reflects the qualitative goals the product has [76]. Once constructs and variables measuring these constructs have been chosen a test study should be designed where participants complete representative tasks for the product(s) [76]. Data for the performance metrics are recorded and processed to be able to draw conclusions on how the concept achieved the desired results [76]. Correct statistical analysis of the recorded data is essential as to make informed conclusions - to answer if the results of the participants can be said to reflect the target demographic at large.

4.11.2.1 Biases in evaluation

On key issue in the context of evaluations are that of biases. Effects on the results which are not actually produced by the artefact and it's characteristics but where the effect is instead caused by the study design or other non-pertinent factors.
- Examples of such biases can be: *Selection bias* - where the participants of the study are not representative of the target population or not randomly selected [77]. *Demand bias* - where the participants understand the purpose of the study and corrects behaviour and answers accordingly to provide the reserachers with their *'desired'* data [78].

4.11.3 NASA-TLX

NASA Task Load Index Questionnaire [80] is a self-reported questionnaire which examines *workload* through the examination of 6 factors. These factors have been empirically tested to reliably estimate the concept of *cognitive workload* [80]. Mental, Physical, and Temporal Demands, Frustration, Effort, and Performance are the relatively independent clusters of variables [80] that are examined to measure the task workload. Each of these variables are tested on a 100-point scale (with increments of 5) and have proven generalize to any activity which demands cognitive attention [81]. The original questionnaire also adds a weighting to each item in the scale, but the raw NASA-TLX variation where the weighting step is skipped is a commonly used and accepted variation [81].

4.11.4 AttrakDiff3

The *AttrakDiff questionnaire* [79] can be utilized to assess the hedonic qualities and pragmatic subjective perception of a product. The evaluation has 4 scales on which a product is understood through, *stimulation* (*HQ-S*) and *identification* (*HQ-I*) which describes hedonic qualities, one that assess its *pragmatic* (*PQ*) qualities and one that examines the *attractiveness* (*ATT*) of the product. These scales are evaluated through a 7-point semantic differential items which a test subject is asked to rate their perceived experience upon. Each construct are measured through 7 word pairings, for a total of 28 items. Examples of word pairings are: *complicated - simple, conventional -inventive, rejecting-inviting.*

The AttrakDiff questionnaire have been used in previous research to assess user acceptance in a study evaluating different types of HMI for motorcycles [25]. Since the project aims to utilise the hedonic/pragmatic model [5] to understand the user experience, evaluation of the resulting artefact(s) with the AttrakDiff questionnaire which targets these constructs are motivated.

4.11.5 Vehicle metrics

To collect data from a vehicle, the researcher can use a *Controlled Area Network* (CAN) logger. This device collects data from the vehicle, for example *velocity* and *battery charge*, which is used to analyze and understand how various compoents of

the vehicle are functioning and communicating with each other [93].

In this thesis, the percentage of hard braking is used as a metric for vehicle control. In a study by Harbluk et al. [84] exploring the impact of cognitive distraction on driving behaviour, the same metric was used. The CAN logger was used in the summative evaluation (chapter **7**) to collect acceleration data from the motorcycle. The acceleration data was then processed using IBM SPSS [88] to extract the metric and analyze the results.

5

Process and execution

In this chapter the process is described in chronological order. The methods used and how they where adjusted and implemented practically to suit the specific domain are presented, as well as conclusions drawn from the activities.

5.1 Literature review

To understand the domain of motorcycling, a literature study of previous research on the topic was conducted. The purpose was explore several domains - interface artifact research in the context of motorcycling, research exploring motorcyclists' behaviours, wants and needs of motorcyclists (human factors) and safety research on motorcycling. Google scholar, Chalmers library and the ACM Digital Library were used. Search terms that were used were, amongst others, 'motorcycling', 'powered two wheelers', 'human factors', 'navigation', 'interface', 'hmi', 'motivations'. Once papers were found new keywords were extracted from those to refine the search further.

The literature review provided knowledge of multiple parts of the motorcycling experience - what entices motorcyclists in the moment-to-moment riding, the underlying reasons for motorcycling as well as safety requirements for HMI design in the context of motorcycling and research surrounding novel navigation assistance solutions. All literature found surrounding the user experience of motorcycling referred to combustion-powered motorcycles.

The findings from the literature review are presented in chapters **2** and **3**.

5.2 Pre-study

The literature review established that previous research pertaining to the UX of motorcycling had only investigated riders of combustion-powered motorcycles. The technical and pragmatic differences between combustion and electric engines entail that the usages differs by such a degree that it can't be assumed that findings from the former can be generalized to the latter. Factors such as *charging time* and *range* alters the experience in such a way that the riders has to approach the activities in different ways. Thus, the project needed to discover and explore novel insights into the user experience of driving electric motorcycles as it has not previously been

researched.

5.2.1 Interviews

Eight (8) semi-structured interviews were conducted remotely with drivers currently using electric motorbikes. Out of these users, six (6) were not owners of RGNT bikes, but rather used other brands such as Zero, Energica and Sondors. The purpose of the interviews were to explore the pragmatic and hedonic sides of riding electric motorcycles, and how navigational assistance was relevant to those. The initial interviews did not pertain exclusively to navigation assistance within the context of electric motorcycling, since the scope for the project needed to be explored at this stage. Furthermore, it is important to note that the initial research goal - "explore navigation assistance in the context of electric motorcycling" is of 'wicked' nature. As a result, insights from seemingly unrelated areas of the context may prove to be significant and provide crucial understanding.

Following the initial four (4) interviews, the results were transcribed and subsequently analyzed utilizing affinity diagramming. As themes and common denominators were discovered in the transcripts, the manuscript for the following four (4) interviews was revised to focus more on the mid-transit user experience of navigation assistance in the context of electric motorcycles. Other themes, such as *route planning*, *preferred types of rides* and *rider identity* were avoided as they were deemed uninteresting as research topics, too broad or unrelated to navigation assistance. A summary of the findings from the affinity diagramming can be found in **Appendix A**.

5.2.2 Convergence

After the interviews had been transcribed and analyzed, a framing of *the future of navigation* needed to be conceived, as this was the initial prompt which RGNT was interested to explore. This in combination with previous research and ideas at RGNT was triangulated to create a concrete and actionable project.

Data from the interviews suggest that motorcyclists generally prefer using integrated HMIs while operating vehicles. In relation to motorcycling and navigation, all participants utilized smartphone applications such as Google Maps, Waze or CaliMoto, as no participant had access to an integrated navigation interface at the time of the interview. The mode for receiving navigation instructions varied however - some exclusively used audio, some exclusively used video and some used both simultaneously. The participants who used video all had some sort of smartphone mount installed on their motorcycles while the participants who only used audio usually put their smartphones in their pocket.

When participants were asked about utilising navigational assistance and how it affected the experience of riding the answer from all of them was that it *is a necessary*

tool, but that it mostly draws the attention away from the riding experience. Participants who used auditory cues argued that it allowed them to focus on the road and surroundings, minimizing the distraction. From these insights it was concluded that communication of navigation assistance through multi-modality was of interest.

"It tells you what to do, it's like a rally car co-driver"
- Pre-study participant describing audial feedback.

Once multi-modality was established as the direction of interest new research papers on the topic were found in the context of motorcycling, specifically papers describing artefacts that provided navigational instructions. From this research it was discovered that vibro-tactile feedback is a previously studied yet seemingly novel approach. According to previous studies, the concept of retrieving and interpreting vibro-tactile navigation assistance when motorcycling is feasible and can provide a pleasurable riding experience. However, all previous studies found were in the context of motorcycles with internal combustion engines. Previous artefact studies opted out of placing the source of the vibrations in the handlebars as the rider's ability to distinguish navigation feedback vibrations from vibrations generated by the powertrain is significantly hindered by the internal combustion engine and the rider's immediate proximity to it. Instead, the vibration source for navigation feedback has previously been placed in areas with low vibration from the system, for example on the lower back via a kidney belt [37] or on the upper parts of the rider's back via a vest [36].

Electric motorcycles in general produce significantly less vibration than their ICE-propelled counterparts. As the vibrations a rider experiences while operating an electric motorcycle are so low, placing the vibration source in a position on the motorcycle historically associated with high system vibration, such as the handlebars, might be possible with an e-motorcycle.

When talking with employees at RGNT, the idea of placing vibration motors in the handlebars had come up. Their idea was to communicate turn-indicators' on or off status to the rider through vibrations. A simple proof of concept with a 3D-printed case for a vibration motor powered directly with a PCU existed at the company. Thus, expanding on that idea to convey navigational instructions was deemed a feasible way forward that aligned with ideas already considered at the company.

RGNT's motorcycles, as previously mentioned, are equipped with a 7" LCD touch screen mounted between the handlebars and a directional joystick as parts of the integrated Human-Computer Interface. This integrated HCI allows the user to carry out simpler tasks with the joystick while in transit. It also allows the user to disregard auxiliary products for their HCI needs - meaning that the user's smartphone can be ignored as a tool for in-transit navigation. Respectively, vibration motors integrated in the handlebars could provide the benefits of multi-modal navigation assistance, without the need for any auxiliary artefact.

Grounded in interviews, previous research and ideas within the company, *integrated*

vibro-tactile navigation assistance feedback was decided as the topic of interest going forward.

5.3   Prototyping

To answer the research questions (section 1.3), the idea of integrated vibro-tactile navigation assistance feedback needed to be evaluated in a real world setting. It was decided that an emulated test rig was not sufficient as an evaluation method, as conceptually, the principle of providing navigational instructions through vibrations were already proven in previous research (see *Chapter 3, Section 3.2*). To evaluate if vibrations generated from road contact was masking the encoded information the prototype needed to be implemented in the actual setting. Furthermore, evaluating the concept on real trafficked roads was reasoned to provide stronger ecological validity of the evaluation results.

For use in tests and evaluations, a prototype (see *figure 5.1* and *5.2*) was developed using the HERE maps Navigate Edition, an android smartphone, an ARDUINO UNO WiFi REV2 microcontroller, two vibration motors and a RGNT No. 1 Classic electric motorcycle. The prototype is able to provide vibro-tactile instruction to the driver based on real world location. Instructions such as turn left, turn right and take the n-th roundabout exit. Details of the implementation can be found in chapter **6**.

Once the prototype was complete it became apparent that the area of focus needed to be the interfacing between the *vibro-tactile navigation system* and the user. As in, how can the system communicate instructions in a way which is understandable and effortless for the user. The issue was conceived to be divided into 2 parts: Can the user reliably perceive the vibrations *and* can they translate - or decode - the instructions reliably.
The initial vibro-tactile encoding implementation of the instructions was based on the HaptiMoto [36] project. The HaptiMoto encoding was conceived in the context of a wearable west that delivers vibro-tactile instructions on the back of the shoulders - and thus needed to be altered to fit in this new context of delivering instructions through the handles. However, it was reasoned that it was a good baseline or starting point for further development.

Figure 5.1: This image shows the prototype mounted onto the handlebars of an RGNT motorcycle. A phone is attached to the left side of the prototype, providing visual navigation. The black box located in the center of the handlebar holds the Arduino, which is connected to vibration motors that are inserted into both the left and right handles.

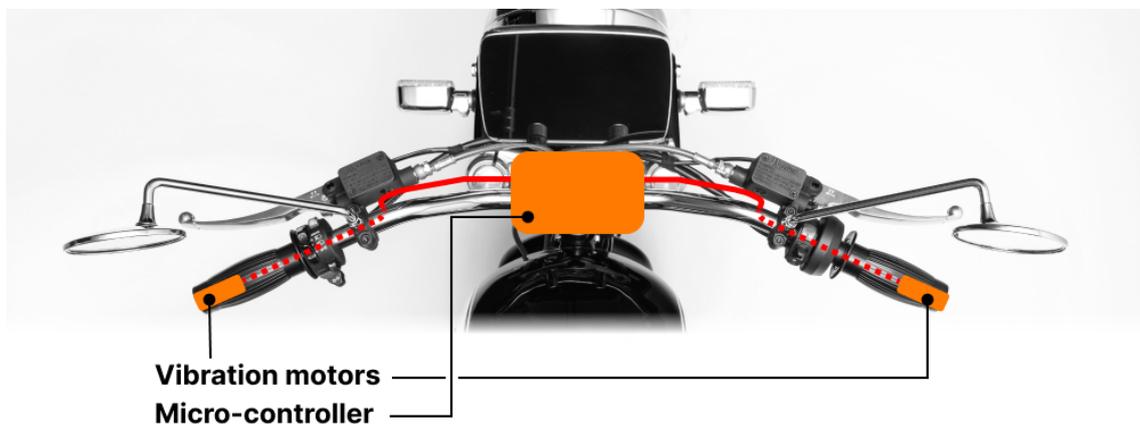**Figure 5.2:** An illustration of the prototypes placement on the motorcycle. Dotted lines refer to internal wiring, solid lines refer to external wiring.

5.3.1 Design iterations

To develop an instruction encoding scheme that successfully delivered instructions an iterative UCD approach was taken. The design space for the delivery and encoding of instructions was broken down into possible design vectors and examined one

at a time. This approach was chosen to be able to understand how changes to one vector - while the others where kept constant - affected the experience for the user. The vectors of the design space were:

- Vibration strength
- Vibration pattern
- Interstimulus interval
- Roundabouts

For each vector of design - design solutions where ideated, implemented and evaluated with users. These evaluation where formative and informed which solution to move forward with. This way, the final concept was developed step by step, with user input between each design decision. A detailed explanation of the process and the design solutions can be found in section **6.4**.

Once all design vectors had been examined and the solution to move forward with was chosen the next step was to evaluate the concept.

5.4   Summative evaluation

With a working physical prototype and a finalized concept for instruction encoding completed an evaluation of result was ready to be performed. An evaluation study was designed with focus on mainly collecting numerical data - such as questionnaires as well as data points collected from the behaviour of the riders during the test. The goal of the summative evaluation was to answer the second research question from section **1.3**. More specifically the questionnaires were AttrakDiff3 and Nasa-TLX, and the data points for objective measurements were *navigational errors* and the percentage of *hard brakes*. These dependant variables were chosen based on previous work done in the domain of automotive, motorcycle and vibro-tactile interface research [90, 91, 84, 36, 37].

The study design and results are motivated and described in more detail in chapter **7**: *Evaluation*. Limitations of the study can be found in section **9.1**.

6

Design and Implementation

In this chapter the hardware and software implementation of the prototype is described. The first iteration of encoding of the instruction is also described. The encoding was the main focus of design during the succeeding work - which is described in section **6.4 - Concept refinement and formative evaluations**. The resulting final concept, *PulsePath*, is described in detail in section **8.1**.

6.1 Hardware

The microcontroller was placed in a 3D-printed case together with the breadboard and attached to the handlebars. Power is supplied to the microcontroller by a powerbank mounted on the outside of the case. From the case cables were initially drawn externally on the handlebars and secured with electrical tape, connecting to the vibration motors from the outside. To ensure that the motorcycle would be operational with the cables connected, extra slack was given to the cable on the throttle-side of the handlebars. Later in the implementation process the hardware was refit, described in section **6.4.5**

Figure 6.1: The first version of the prototype in its case, mounted on the handlebars of a RGNT motorcycle.

The placement of the vibration motors in the handlebars was considered most feasible as they needed to be placed in a position where the rider has physical contact

with the motorcycle. Other positions considered were the foot pegs, "tank" and the seat of the motorcycle. Placing the vibration motors in the foot pegs was discarded as it would require much stronger vibration motors for the vibrations to permeate through the soles of the rider's shoes, placement on the tank was discarded as it is not a place of constant contact and placement in the seat was discarded since discerning direction might have been hard for the rider.

6.2 Software

To retrieve positioning data and for setting up a basic navigation smartphone app, HERE maps was used to create an android Flutter application. HERE is a service which provides map data and navigational instructions. They offer a software framework called *HERE maps navigation edition* - which provides developers with map data, points of interest, and functionality with the ability to provide point-to-point navigational instructions. In the project, we were given access keys to the paid version by RGNT in order to be able to utilize these features. The android software for the prototype was built with the HERE maps navigate SDK as the base - specifically a modified version of *HERE SDK Reference Application for Flutter* available on GitHub [89]. The android app then was connected to the Arduino through low energy Bluetooth, which in turn controls the vibration motors. Figure **6.2** describes the data flow from HERE maps to the Arduino.

The application could also have been built using other navigation APIs, and was initially built using Mapbox [92]. However, these APIs did not give full access to the data needed, most importantly the distance between user and navigation event, to create a fully functioning prototype.
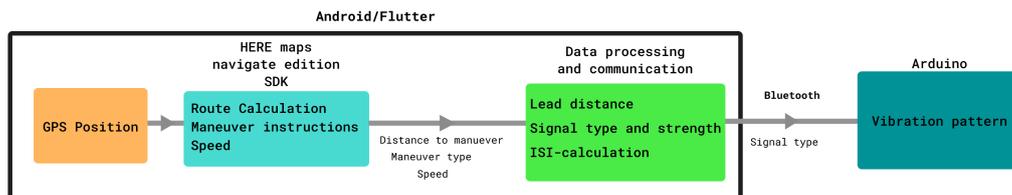
Figure 6.2: Illustration of the flow of data inside the software. Inside the blocks description of processed information is shown. Under the arrows, what data is sent to other modules is described.

When HERE maps SDK is given departure and destination locations, it generates a route to the destination. The route consist of *maneuvers* such as 'turn left', or 'take the third exist in the roundabout'. The SDK also provides data on how far ahead in meters the maneuver need to be executed in real time. This data along

with current speed is sent to a evaluation layer inside flutter (see *data processing and communication* in **figure 6.2**).

In the evaluation layer, this data is processed to determine if the vibration motors should be activated. Further, the type of maneuver and the strength this signal should have is determined. For instance, this could evaluate that an "immediate left turn signal" should be activated. This data is then encoded into bytes and sent to the Arduino via low energy Bluetooth by using the *Flutter blue* library.

The Arduino constantly listens for an activation signal, once received the vibration pattern that corresponds to the maneuver and strength is activated - subsequently powering the vibration motors.

6.3 Initial vibrotactile encoding of instructions

The application was programmed to react whenever the driver reached a multiple of the lead distance (equation 6.1) from a navigation event (i.e. turning left or right or using the nth exit of a roundabout) and send signals to the microcontroller through Bluetooth. Subsequently, the microcontroller interprets the signals and relays different vibration patterns through two Precision Microdrives 308-106.001 vibration motors [83] inserted into 3D-printed casings, one on each end of the handlebars.

$$Lead\,distance(X)m = km/h * 1.1973 + 21.307 \qquad (6.1)$$

The vibration pattern indicating proximity to navigation event was initially chosen to mimic the pattern presented in the HaptiMoto project [36], as the participants of that study could both perceive and understand the vibration cues and navigate accordingly and successfully. However, as there is a difference in the placement and type of the vibration motors, the vibration pattern used in this project differs slightly from that presented in the HaptiMoto project [36]. As the user reaches different distances from the navigation event, the vibro-tactile feedback changes as follows (visualized in figure 6.3) :

1. **4 × Lead distance:** A single 500ms pulse, repeated every 3 seconds.
2. **2 × Lead distance:** Two 300ms pulses, separated for 100ms, repeated every 3 seconds.
3. **1 × Lead distance:** Three 300ms pulses, separated for 100ms, repeated every 3 seconds.

The direction of the maneuver was encoded into the corresponding handle - if the driver should turn left only the left handle vibrates, and vice versa for a right turn.
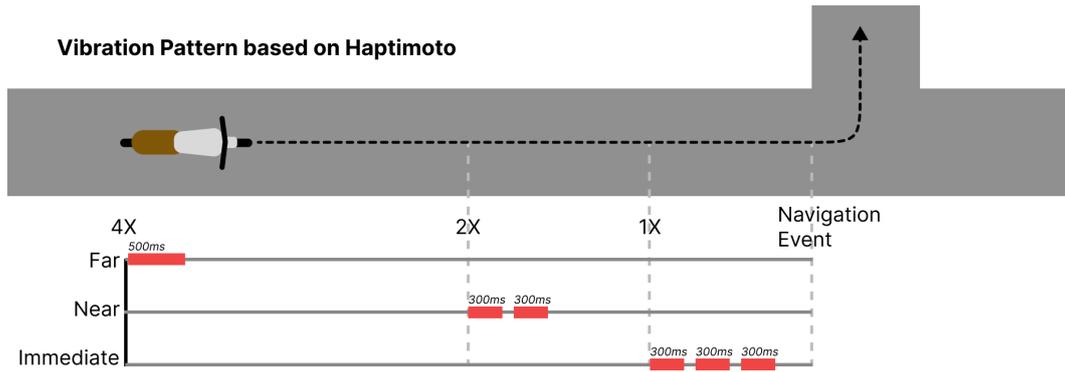
Figure 6.3: The initial vibration pattern, based on the Haptimoto vibration pattern.

6.4 Concept refinement and formative evaluations

Before using the prototype in the evaluative test, the prototype itself went through a number of iterations and tests as part of the design process.

6.4.1 Basic functionality

To evaluate the functionality of the prototype, two RGNT employees were recruited as participants for real-world testing. Two tests were conducted - one to test if the vibrations could be felt while riding and one to test if the vibrations were distinguishable and understandable. The signal pattern was as follows, with three seconds between signals of the same type:

Proximity	Far	Near	Immediate
Pulse (ms)	500	300	300
Interval (ms)	–	100	100
Repetitions	1	2	3

Table 6.1: Vibration pattern for initial test

First, one participant took a trip on a *RGNT No. 1 Classic* e-motorcycle with the prototype set to repeat a loop of the signal pattern above. The participant was instructed to ride, safely, at different velocities and return with feedback on the tangibility of the vibrations at varying levels of road vibration. The participant stated that the vibrations were harder to distinguish as the vibrational noise increased, especially at speeds over 90 kilometers per hour. They also stated that it was hard to distinguish the different signals from each other.

Second, the other participant was instructed to follow a preset route using the vibration feedback as guidance. They were presented with the route beforehand and

asked to bring feedback on how understandable the different signals were. The main takeaway from the second test was that the participant found it difficult to differentiate between signals in close succession, meaning that when the interval between signals became too short, it was perceived as a single signal of 5 pulses rather than a signal of 2 pulses followed by a signal of 3 pulses.

The feedback from the initial tests lead to further design of the prototype. To mitigate the loss of tactility at high speeds, the voltage to the vibration motors was increased from 3 to 5 volts, increasing both the frequency and amplitude of the vibrations [83]. The issue surrounding the differentiation between signals was tested further, as is described below.

6.4.2 Vibration pattern

To explore which type of vibration pattern to use in the final test, different versions of the signal were tested on three participants. The different patterns varied in two aspects in relation to the proximity to a navigation event- *pulse length* and *repetitions*. The different versions tested were as follow:

Version A	Far	Near	Immediate
Pulse (ms)	500	300	300
Interval (ms)	-	100	100
Repetitions	1	2	3
Total duration (ms)	500	800	1200

Table 6.2: Vibration pattern A - increasing number of repetitions

Version B	Far	Near	Immediate
Pulse (ms)	150	250	800
Interval (ms)	-	-	-
Repetitions	1	1	1
Total duration (ms)	150	250	800

Table 6.3: Vibration pattern B - increasing pulse length

Version C	Far	Near	Immediate
Pulse (ms)	150	300	600
Interval (ms)	-	150	300
Repetitions	1	2	3
Total duration (ms)	150	900	2400

Table 6.4: Vibration pattern C - increasing pulse length and increasing number of repetitions

The participants were given a brief presentation of the vibration patterns, the order of which varied between participants, and instructed to follow a predetermined 6km route. The tests were conducted without the aid of any other mode of navigation. After returning to the starting point, the vibration pattern was changed and the process repeated. After all versions had been tested, the participants were asked for feedback surrounding the different patterns.

Moving forward, it was decided that a modified version of Vibration pattern C (table 6.4) was to be used. The singular pulses used for communicating "a maneuver will need to be performed" in all versions tested were described as hard to distinguish from an anomaly in the road surface. Similarly, vibration pattern B (table 6.3) was the least preferred by the participants for that reason. It was also noted that the signals with the longest pulse lengths (600 & 800ms) were perceived as intrusive and produced an uncomfortable sensation in the participants' hands. Vibration pattern C also had a total signal length of 2400 ms for the longest signal which lead to the signal sometimes being perceived as being triggered mid-turn.

Version D	Far	Near	Immediate
Pulse (ms)	100	200	400
Interval (ms)	100	150	200
Repetitions	2	2	3
Total duration (ms)	300	550	1600

Table 6.5: Vibration pattern D - increasing pulse length and increasing number of repetitions. A modified version of vibration pattern C (Table 6.4)

The resulting vibration pattern is shown above in table **6.5**. The *Far* signal, communicating that a navigation event is coming up, consists of two 100ms pulses separated by a 100ms interval to provide separation from vibrations produced by road surface anomalies. The *Near* signal, communicating that the navigation event is closer, also consists of two pulses, however the change in pulse length and interval makes it distinguishable from the *Far* signal. Lastly, the *Immediate* signal, communicating that the maneuver should be made as soon as possible, consists of three 400ms pulses separated by intervals of 200ms. The difference in *pulse length* and *repetitions* makes the signal distinguishable from all others, while still being short enough as to not vibrate through a turn.

6.4.3 Interstimulus interval

After the vibration pattern had been determined, the interstimulus interval, or *ISI*, needed exploration to mitigate the issue with participants interpreting signals in close succession incorrectly. In the Haptimoto project [36], this issue was corrected by limiting the interval between GPS updates so the time between signals was controlled by the distance travelled and the time between signals simultaneously. However, the signals used in the Haptimoto project [36] all had a pulse length of

300ms and communicated turn proximity by increasing the amount of pulses per signal, similar to vibration pattern A shown in table **6.2**. Since the pulse lengths and intervals within signals were identical, the problem with two signals in close succession being interpreted as a single, longer, signal could possibly be mitigated by varying the pulse length as shown in tables **6.3**, **6.4** and **6.5**. Therefore, we felt it necessary to test two different types of ISI - one that is only controlled by navigation event proximity, version A (figure **6.4**), and one that is controlled by both navigation event proximity and time elapsed since last signal, version B (figure **6.4**).
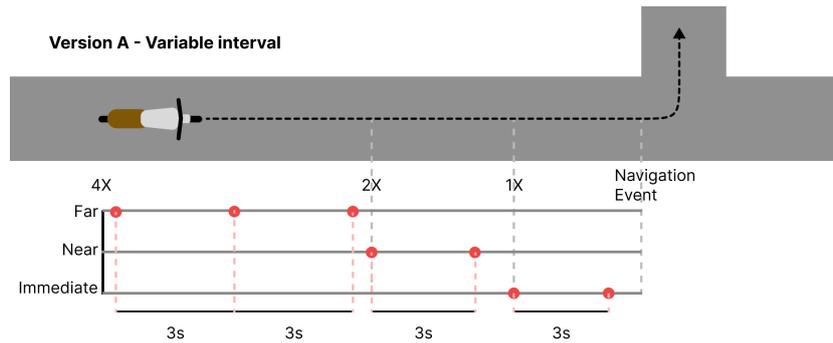
Figure 6.4: An illustration of the *Variable interval* version of the ISI, where X is the *lead distance* from the navigation event and "Far", "Near" and "Immediate" relate to the different signal types.
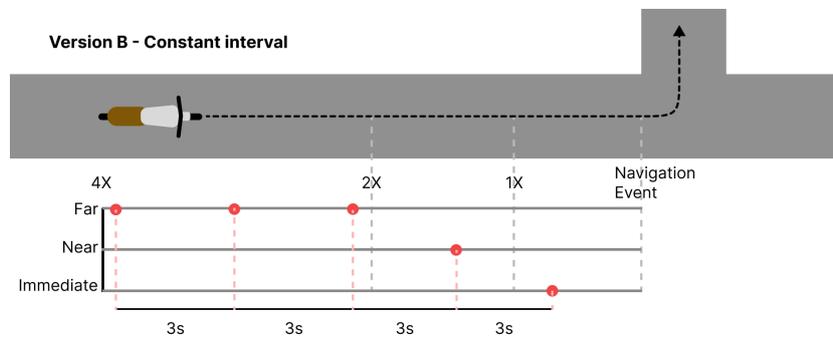
Figure 6.5: An illustration of the *Constant interval* version of the ISI, where X is the *lead distance* from the navigation event and "Far", "Near" and "Immediate" relate to the different signal types.

In version A - *Variable interval*, illustrated in figure **6.4**, the ISI is three seconds only within the same signal type. As soon as the driver reaches a change in lead distance multiple, the corresponding signal is communicated through the vibration motors.

In version B - *Constant interval*, illustrated in figure **6.5**, the ISI is three seconds regardless of the timing of the driver reaching the different lead distances from the navigation event. With this version, no signals appear in direct succession of each

other.

Similarly to the vibration pattern, described in section **6.4.2**, the ISI was tested on two participants. The participants were given a brief presentation of the difference between ISI version A and B and instructed to follow a predetermined route. The participants tested the different ISI versions in different order. Following the test, the participants were asked for feedback and it was decided that version A should be used going forward as the participants were able to understand the signals even when they appeared in close succession, indicating low risk of both misinterpretation of different signals and late delivery of the "Immediate" signal due to a constant ISI.

6.4.4 Extended functionality - roundabouts

Following the test of vibration patterns (section 6.4.2), it was decided that the functionality of the prototype should be extended to not only communicate left- and right turns but also include roundabouts, as this would open up the possibility for longer, more complex test routes to be used in the final evaluation.

The design of the signal used for communicating which exit to use in a roundabout took inspiration from the MOVING project [37]. In MOVING [37], it is determined that roundabout instructions differ from turn instructions in that they do not need to communicate distance or direction as the driver only needs to know which exit to take. The signal used in MOVING is therefore set to 500ms pulses with all vibration motors separated with intervals of 500ms, where the number of pulses indicate which exit to use [37].

In the prototype, the *Far* signal of two 100ms pulses was used for communicating that the rider was approaching a roundabout, followed by a number of 300ms pulses (separated by 300ms intervals) relating to the exit number. To distinguish the roundabout signal from regular left/right turn signals, both left and right vibration motors were activated. As was discovered during the vibration pattern test (section 6.4.2), longer total signals were perceived as annoying, why the pulses and intervals are shorter than the ones used in MOVING [37].

Roundabout	Far	Near	Immediate
Pulse (ms)	100	300	300
Interval (ms)	100	300	300
Repetitions	2	VAR	VAR
Total duration (ms)	300	VAR	VAR

Table 6.6: Vibration pattern for roundabouts. The amount of repetitions per signal correlates with the suggested exit. The third exit in a roundabout would be indicated by 3 repetitions for instance.

Since the pulse length and interval between pulses are the same regardless of the rider's proximity to the roundabout, the problem of multiple signals in close proximity being perceived as a single, longer signal appeared in the signal pattern for

roundabouts. Therefore, the ISI is set to *constant* (see figure 6.5) for roundabouts. The extended functionality was also tested by two participants. The participants were introduced to the purpose of the test and set out to follow a route that contained a number of roundabouts, where the rider would take different exits for different roundabouts. Upon returning, the participants were asked if they understood the signals. The functionality was deemed fully understandable, and was included in the final evaluation of the prototype.

6.4.5 Refit

Due to unforeseen circumstances, the construction of the prototype had to be reiterated. To be able to transfer the prototype between individual motorcycles without damaging the ends of the grips, the vibration motors were routed internally in a set of handlebars, illustrated in figure **6.6**. This allowed for the prototype to be moved between motorcycles with a quick reassembly of brake handles, throttle, and rear-view mirrors.
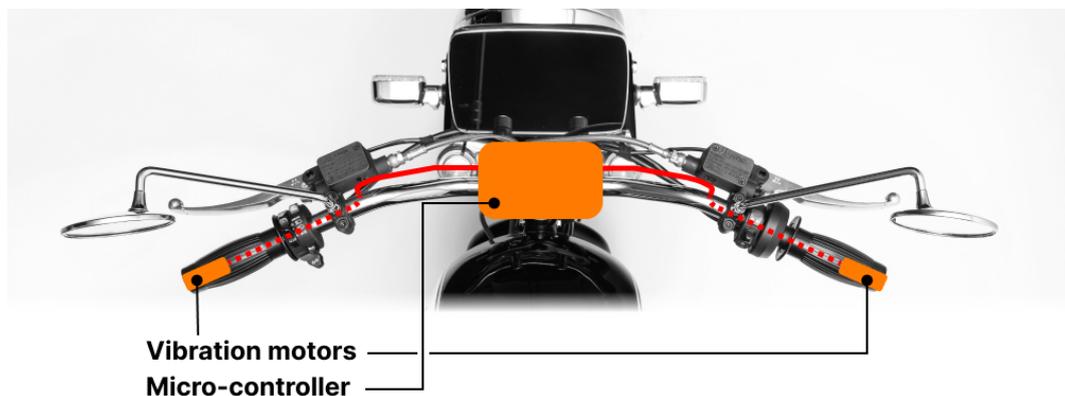
Figure 6.6: An illustration of the final version of the prototypes placement on the motorcycle. Dotted lines refer to internal wiring, solid lines refer to external wiring.

At first, the vibration motors were placed internally in a pair of "motocross" style handlebars. With these handlebars however, the vibrations propagated in a way that made it impossible to discern whether it was the right- or left motor that vibrated, possibly because the handlebars had a cross brace where the original handlebars were without. This issue was not investigated further, and the vibration motors were placed in a pair of handlebars without cross brace.

7

Evaluation

To answer the second research question - *How does using the vibro-tactile navigation assistance feedback provided by PulsePath affect the riding experience?* - the PulsePath prototype was evaluated in a real-world driving test on trafficked roads surrounding Kungsbacka. A detailed description of the prototype can be found in section **8.1**. The independent variable (IV) was the mode of receiving navigation instructions - a baseline was chosen as only using the visual *GPS based map* which was then compared to using both *visual* and *vibro-tactile* feedback in conjunction. The idea of a comparison between using only visual navigation and only using vibro-tactile feedback as the different IV's was discarded as the vibro-tactile system was not conceived to be a stand-alone instruction system. Thus any findings from such an evaluation would not have any real world implications. For dependant variables cognitive workload, driving style, navigation performance, and user experience were chosen.

7.1 Study design

The study was conducted on roads surrounding Kungsbacka on weekdays with time of day varying from 10:00 to 16:00 to ensure that the results were produced in a realistic setting and to provide ecological validity to the evaluation. A within-subjects approach was chosen for the procedure as to account for individual differences - such as driving experience or familiarity with the roads in the area - and increase statistical power. By using the same participants for both conditions, the study reduced the potential for confounding variables and achieved a greater level of precision with fewer participants - as the participant selection was limited to RGNT employees due to insurance reasons. This ensured that the results of the study would be both reliable and valid.

Two routes (see figure **7.1**), A and B, were set up which the participants were asked to navigate along during the test. Both routes were of similar length (23 minutes according to the HERE maps approximation) and had a similar amount of maneuvers - i.e. turns and roundabouts. Both of the routes included country roads (60 - 90 km/h) and city driving (20-50km/h). Highways and cobblestone-paved roads were not included as it would increase the duration of the test rides and the scope of the study respectively. The participants had to receive instructions at high speeds on country roads on both routes. There were also sections were participants had to perform a chain of maneuvers in close succession at low speeds in both routes.

Route A departed from RGNT's office and concluded at a parking lot in central Kungsbacka. Route B was the initiated from this parking lot and ended back at RGNT's office. A study design where the same route were traveled twice, with the different modes of navigation was discarded, as the participants would be able to navigate by memory the second trip and thus invalidate the data. Furthermore, navigational assistance is used when the user is uncertain or don't know the directions to the destination, so as to give the study ecological validity the trips needed to be unknown for both conditions.
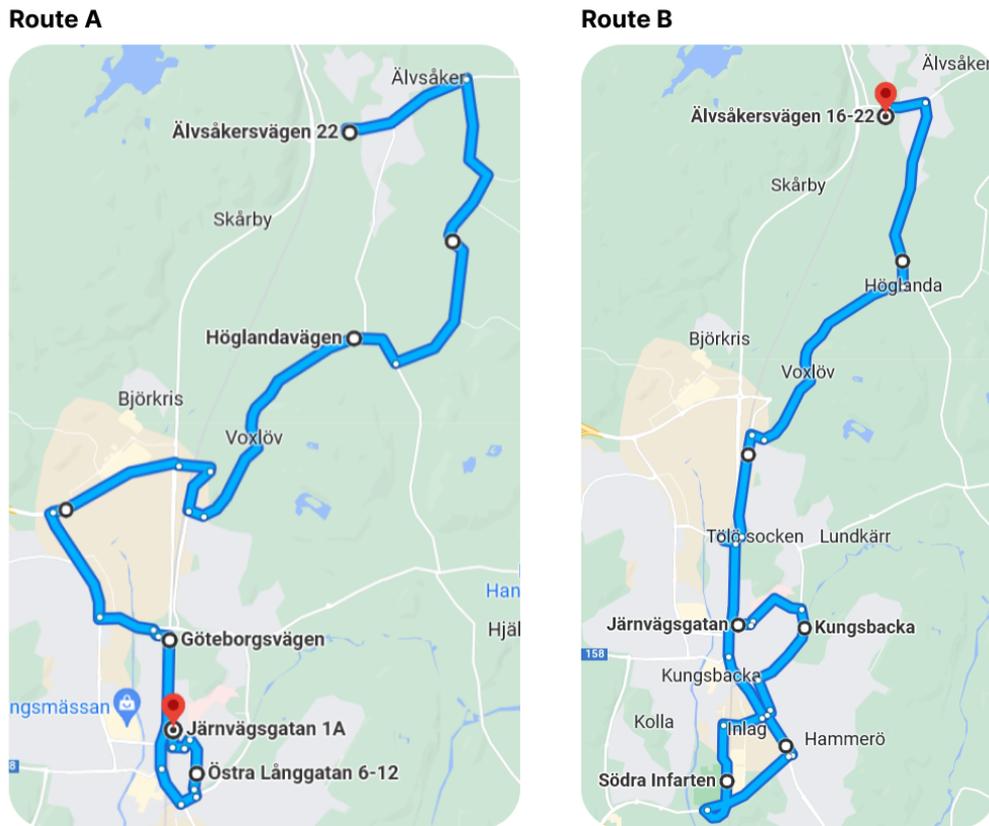
Figure 7.1: The two routes used for evaluation. The routes have similar characteristics in terms of amount of turns and roundabouts as well as roads with different speed limits. Source: Adapted from *Google Maps* [87].

An AB/BA crossover design, with a randomized order for the first evaluation and alternating for the following, was employed where each participant either drove route A with visual and vibro-tactile feedback and route B with only visual feedback (n=5) *or* route A with only visual feedback and route B with visual and vibro-tactile feedback (n=5). This decision was done to mitigate any confounding effects of the differences in the routes' characteristics would have on the data.

7.1.1   Dependent variables

To answer the research question *"How does using vibro-tactile navigation assistance feedback effect the riding experience?"*, two aspects were considered of interest to answer it thoroughly - the usability and the user experience of the system. To evaluate the usability the *amount of navigation errors* was used to measure navigation performance and the *amount of hard braking* was recorded to assess vehicle control, and the *NASA TLX* questionnaire [80] was used to assess changes in workload. The *amount of navigation errors* were counted during testing and compared between the feedback modes of navigation (PulsePath or visual-only) for each participant, similar to the evaluation used in the MOVING project [37]. A navigational error was defined as missing a turn, or taking the wrong exit in a round-about.

For the *amount of hard braking*, acceleration data was collected from each trip and analyzed using IBM SPSS [88]. Any negative acceleration larger than 0.25 g-forces ($a = 2.4525\frac{m}{s^2}$) was defined as *hard braking* as per Harbluk et al [84]. To account for the participants' individual driving styles, the amount of hard braking was compared between the modes of navigation for each participant. The difference in *amount of hard braking* was then used as the metric for *vehicle control*.

The *NASA-TLX* questionnaire [80] was employed to assess differences in workload between the two modes of navigation assistance. The questionnaire lets the participants rate the workload of a task, in this case *navigating a route while riding an electric motorcycle*, in six subscales:

- Mental demand
- Physical demand
- Temporal demand
- Performance
- Effort
- Frustration

One of the hypothesised issues was the divided attention between focusing on the road and on-screen visual navigational instructions. With the multiple resource model as a framework it was hypothesised that the shared visual processing of traffic and reading navigation instructions would increase the mental workload of the drivers - where as vibration feedback would decrease the mental workload relatively, as the instructions could be received without calling on visual cognitive resources. Furthermore, a decrease in attention toward the screen could, as Leshed et al. [12] argues, increase the presence and connection to the world around them. Thus, a change in mental workload could also be used to evaluate and argue a shift in the hedonic experience.

The second aspect of interest was the user experience, viewed through the lens of Hassenzahl's hedonic/pragmatic model [5]. For this the AttrakDiff3 questionnaire was utilized to gather subjective self-reported numerical data. To be able to qualitatively explain the gathered data short interviews gathered experiential reports from

the participants post-test ride.

For statistical analysis of the gathered data IBM SPSS [88] was used.

7.2 Participants

We recruited *n=10* participants for the evaluation, all of which employees at RGNT motorcycles and recruited through internal communication channels. The participants' ages varied between 24 and 48 (*M = 33.1, SD = 7.9*), time of motorcycle experience between 1 and 25 years(*M = 10.7, SD = 8.1*) and estimated yearly motorcycling distance between 1000 and 10000 km (*M = 3861.1, SD = 2886.1*).

7.3 Apparatus

A RGNT No. 1 Classic electric motorcycle was used in the evaluation, with the *PulsePath* prototype attached to the handlebars, together with a OnePlus android smartphone for visual navigation feedback (shown in figure **7.2**).

Figure 7.2: Photograph of the PulsePath prototype mounted to the handlebars, together with the smartphone used for visual feedback. The integrated HMI visible above the 3D-printed case provides information about battery level, velocity and system vitals to the rider. When seated on the motorcycle, this screen was visible to the riders.

The settings for PulsePath used in the evaluation, in regard to *vibration instruction encoding, interstimulus interval* and *vibration patterns* are described in detail in section **8.1**. When using PulsePath, both vibro-tactile and visual navigation feedback is provided to the rider. The navigation software used for visual navigation feedback

was a version of HERE maps smartphone application "HERE we go" (screenshot shown in figure **7.3**).
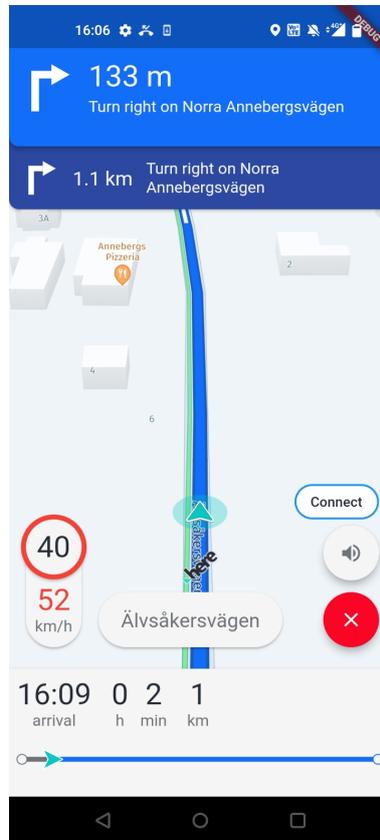
Figure 7.3: Screenshot from the visual navigation feedback application. In this screenshot PulsePath is not connected, as indicated by the color of the 'Connect' button on the right side of the screen.

7.4 Procedure

After an introduction to the purpose and goal of the study, the participant were introduced to the mode of navigation feedback (PulsePath *or* visual-only) they would be given for the first trip. The introduction for PulsePath included visualisations of the vibration patterns (see figure **7.4**) as well as feeling the vibrations through the handlebars at a standstill. They were then asked to follow the navigation instructions for route A to the end point. Once the participant reached the destination, participants were asked to fill out both a NASA-TLX and an AttrakDiff3 questionnaire relating to the first trip.

(a) Turn visualisation

(b) Roundabout visualisation

Figure 7.4: Visualisation of the vibration instruction encodings. Shown to participants before they used the system.

An instructor then changed the mode of feedback and the participant were introduced to the new mode of navigation feedback (PulsePath *or* visual-only). The participant was then asked to follow the navigation instructions for route B. Once at the final destination, participants were once again asked to fill out the NASA-TLX and AttrakDiff3 questionnaires, but for the second trip. Particip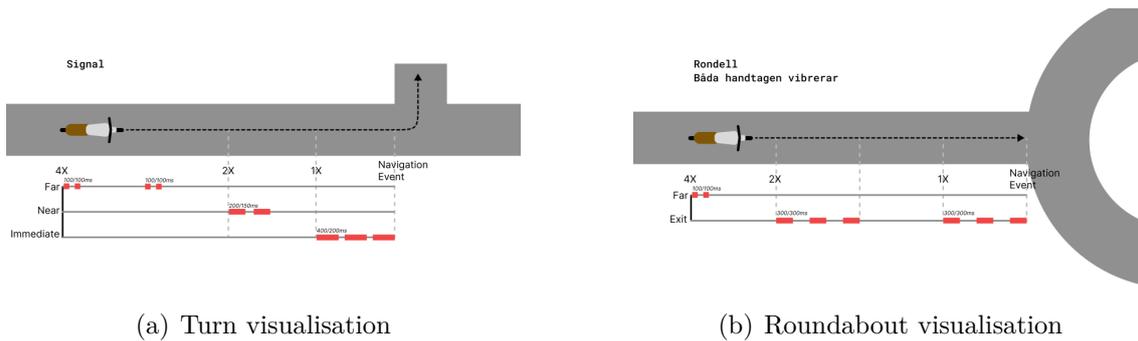ants were then asked 3 interview questions about the difference of experience and usage between the systems. No probing was employed. The 3 questions were:

- How did you perceive the driving to differ between driving with only a map and with the vibrotactile feedback?
- Did you experience any difference in how you directed your attention between the different modes?
- Other thoughts?

To observe the participants en route and provide assistance if needed, the participants were followed by two instructors in an automobile. The number of navigational errors were noted. If the participants performed an incorrect maneuver and did not indicate to the follow car that they were aware of the error their attention was called upon (honked) and they were guided back on to the route.

7.5 Results

In this section the quantitative results from the braking data, amount of navigation errors, NASA-TLX and AttrakDiff3 questionnaires are presented, as well as a summary from the post-ride interviews. For navigation errors and NASA-TLX 10 participants' data were processed and analysed. Due to data loss only 9 participants data was recorded and analysed for AttrakDiff3 and braking data. The data loss was caused by error in the CAN-Bus logger and lost internet connections. Wilcoxon signed-rank tests were applied for most data due to the low number of participants (n=10, n=9). Chi-square tests were employed to measure PulsePath's impact on braking, as well as the different routes' impact on braking. A two-sided t-test was used on the raw Nasa-tlx data as the wide adoption of the test and previous research has shown that the resulting data assumes normality [81].

7.5.1 Impact on braking

When analyzing PulsePath's impact on braking overall with a chi-square test, a small but statistically significant decrease (-0.4%, $p < 0.001$, $df = 1$) was shown in the percentage of hard brakes, i.e. a deceleration larger than $2.4525\frac{m}{s^2}$.

To account for individual riding styles, the difference in hard braking for each participant when using the different feedback modes was compared using a Wilcoxon signed-rank test. The analysis showed no significant change in PulsePath's impact on braking ($p = 0.515$, Z = -0.652). Due to technical errors, brake data was only collected for 9 of the 10 participants.

When analysing the different routes' impact on braking with a chi-square test, it showed identical results to the feedback modes' impact, i.e. a decrease in hard braking by 0.4% and $p < 0.001$, $df = 1$.

7.5.2 Navigation errors

In general, the riders made less navigation errors when using PulsePath (*Min = 0, Max = 1, M = 0.4, SD = 0.6*) than when using only visual feedback (*Min = 0, Max = 3, M = 1, SD = 1.05*). However, a Wilcoxon signed-rank test showed that the mode of navigational instructions had no significant impact ($p = 0.161$, Z = -1.403) on the amount of navigation errors.

7.5.3 Raw NASA-TLX

To measure the workload for each feedback mode, the Raw NASA-TLX method was used (section **4.11.3**). Using a two-sided t-test, the analysis of the data showed a significant difference in overall workload between the two feedback modes ($t(9)$ = -2.975, $p = 0.021$). PulsePath had a lower workload (*M = 144.5, SD = 77.9*) than the visual feedback (*M = 254.5, SD = 95.5*).
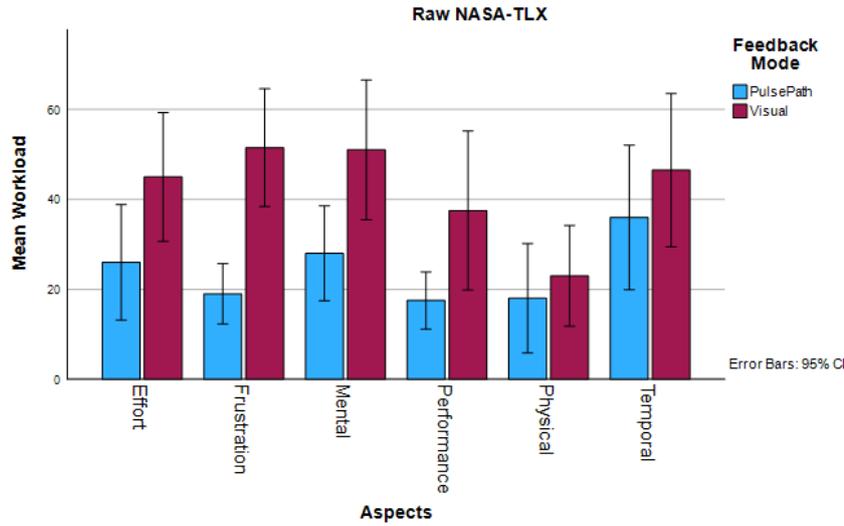
Figure 7.5: Comparative bar chart of the mean workload score for each NASA-TLX subscale. Scores for PulsePath is shown in blue and scores for visual navigation feedback is shown in purple. Error bars show 95% confidence interval.

Examining the individual subscales with a Bonferroni correction ($p < 0.025$), significant difference was only shown in *frustration* ($t(9) = $ -4.422, $p = 0.002$), with *mental workload* ($t(9) = $ -2.588, $p = 0.029$) and *effort* ($t(9) = $ -2.646, $p = 0.027$) nearing statistical significance. Least significance was shown in *physical workload* ($t(9) = $ -0.707, $p(9) = 0.497$). Figures **7.5** and **7.6** show the mean workload scores and the individual participants' difference in workload scores respectively.
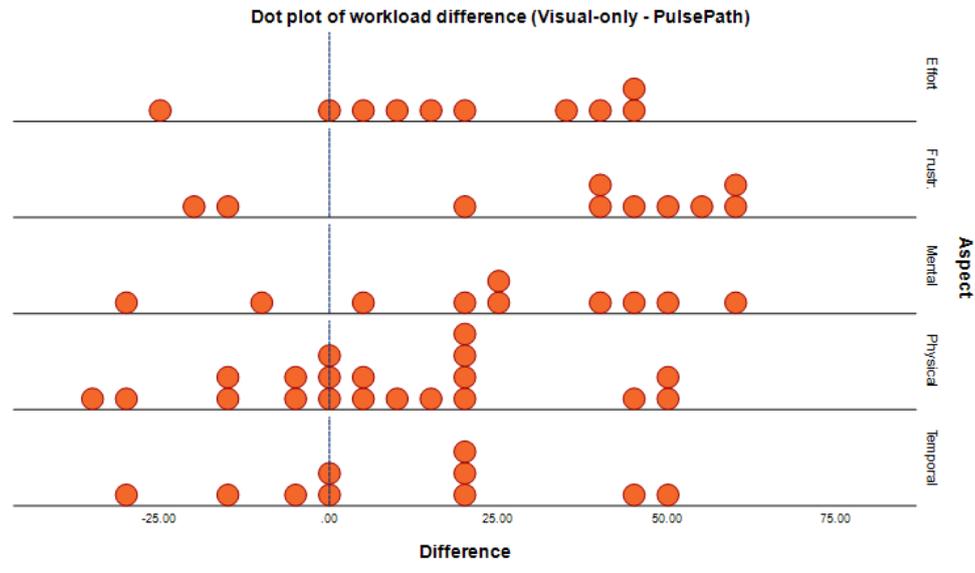
Figure 7.6: Dot plot of each participant's difference in workload score between feedback modes per aspect, where each dot represents a participant's rating of a specific aspect. The vertical line represents no change in workload between feedback modes. Dots to the right of the line indicate a difference in favor of PulsePath, and dots to the left indicate a difference in favor of visual-only feedback.

7.5.4 AttrakDiff3

The AttrakDiff3 questionnaire (section **4.11.4**) was employed to measure the subjective user experience in relation to four different qualities - pragmatic, hedonic-identification, hedonic-stimulation and attractiveness. Only 9 of 10 participants answered the questionnaire.

Using a Wilcoxon signed-rank test, statistically significant differences was shown for all four qualities ($p < 0.001$, $Z < $ -5.377). Visualizations for the results are shown below in figures **7.7**, **7.8** and **7.9**.
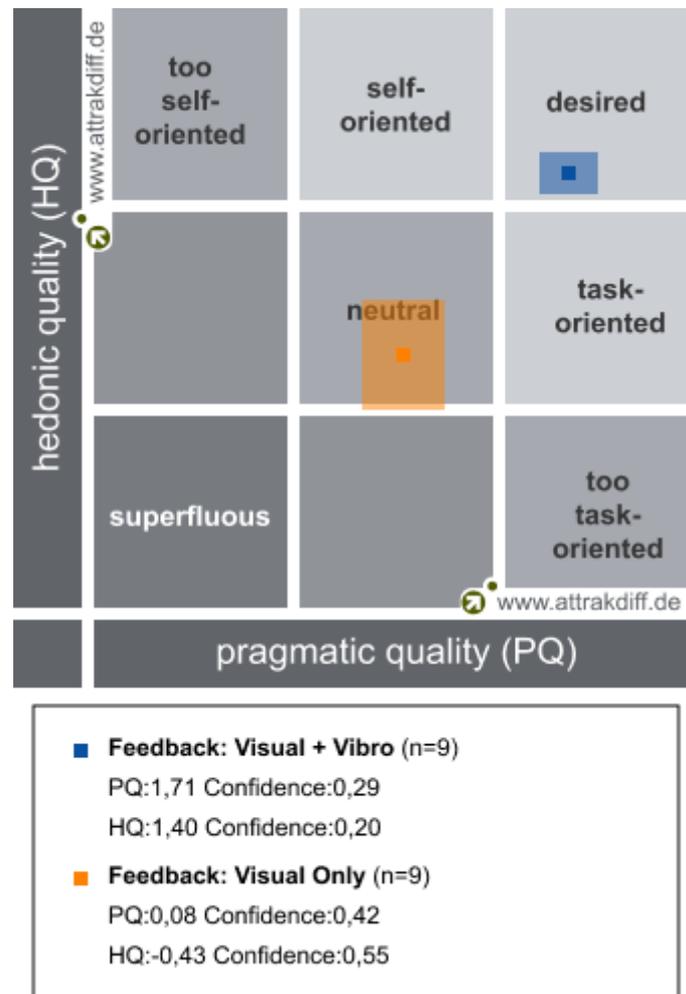
Figure 7.7: Visualization of the results from the AttrakDiff3 questionnaire. PulsePath is shown as the blue square and screen-only navigation is shown in orange. Inside the 9-panel grid overall product characteristics are described. Source: *AttrakDiff.de* [86]

47
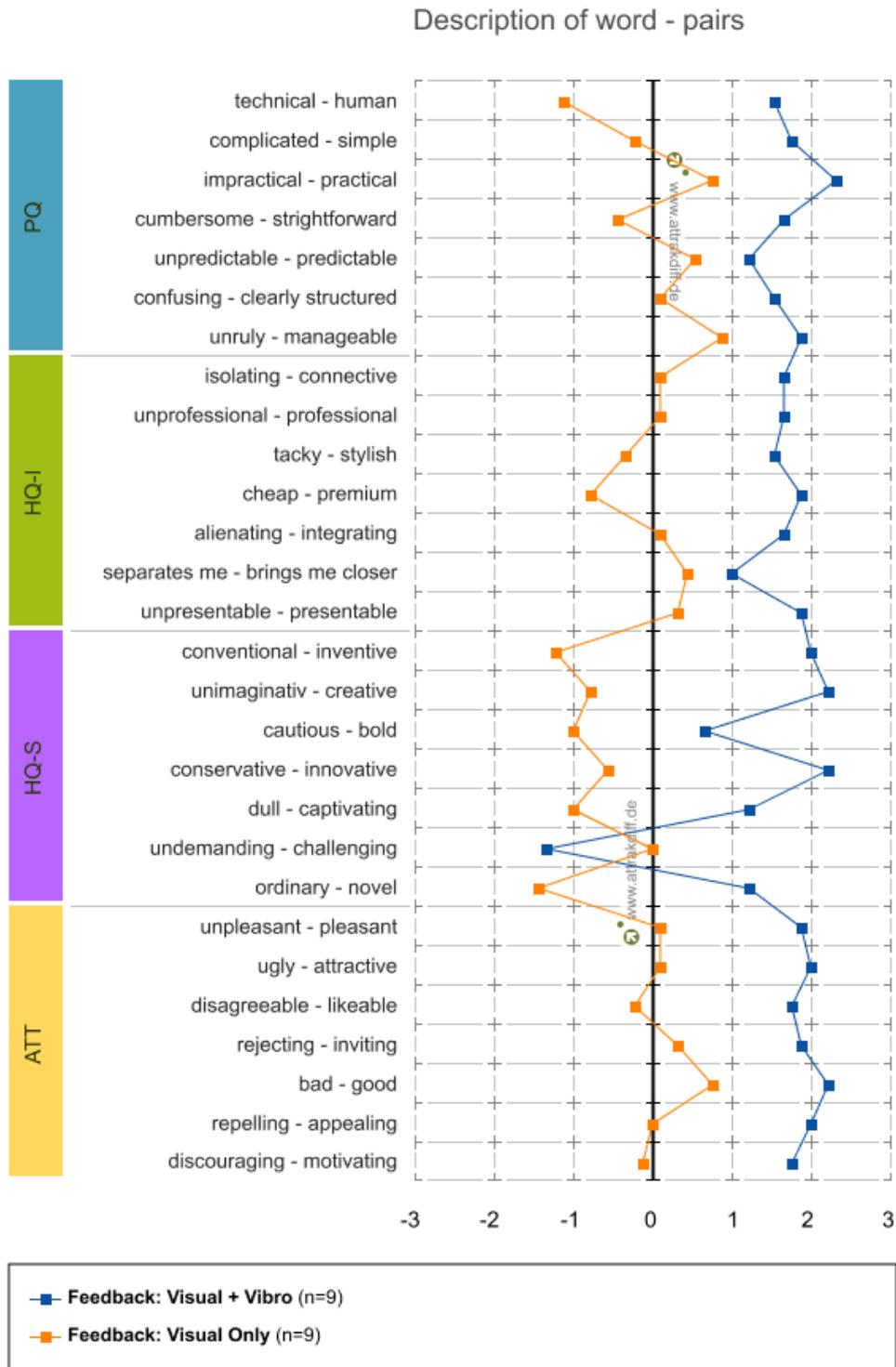
Figure 7.8: Visualization of the word-pairs used in the AttrakDiff3 questionnaire, as well as the average rating for each word-pair. PulsePath is shown as the blue line and screen-only navigation is shown in orange. Source: *AttrakDiff.de* [86]
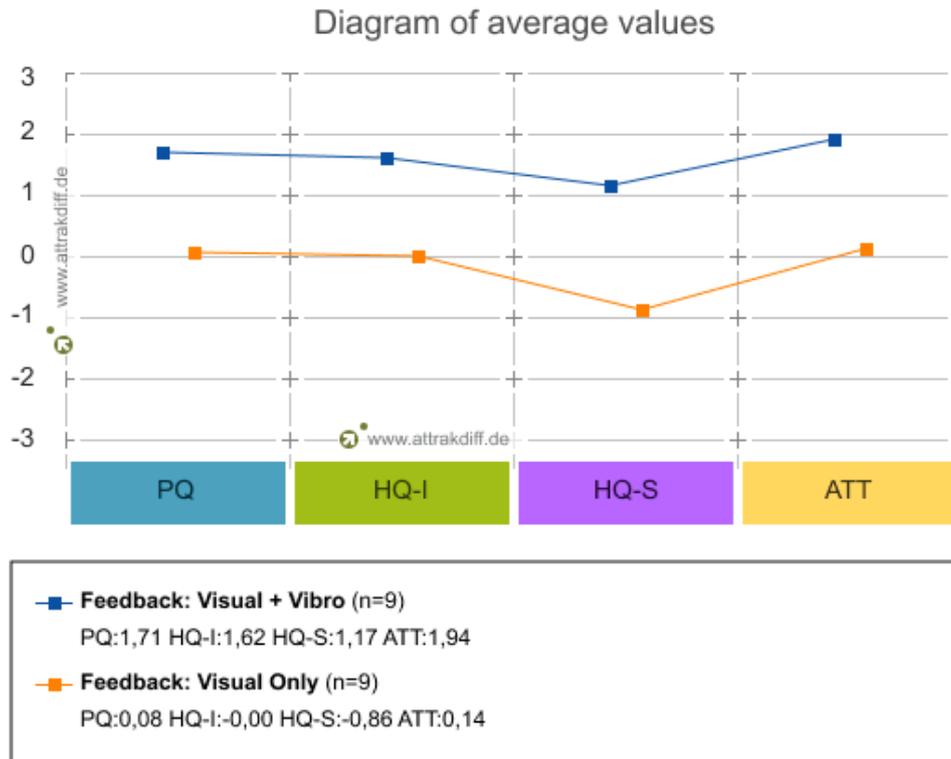
Figure 7.9: Diagram of the average values for the different feedback modes from the AttrakDiff3 questionnaire. PulsePath is shown as the blue line and screen-only navigation is shown in orange. Source: *AttrakDiff.de* [86]

7.5.5 Interviews

In this section the data collected from the post-ride interviews are presented. This section is a summary of the opinions gathered from the interviews that were conducted immediately after the participants had performed the study. The raw transcripts from these interviews are omitted from this report.

When asked about how the vibro-tactile feedback affected the motorcycling experience, all participants answered positively. The vibro-tactile feedback helped them direct their attention to their surroundings, making riding in traffic feel safer compared to navigating with visual feedback only. Since PulsePath is 'active' in the sense that it calls on the rider's attention when a navigation event is approaching, some participants expressed that they felt more relaxed while riding and that PulsePath gave instructions only when relevant. One participant stated that PulsePath made them feel more connected to the motorcycle than when using only the visual feedback.

> *"Navigating with the vibrating handlebars kept my vision on the traffic instead of scanning elsewhere. Made me feel a lot safer. It eliminated a big risk - you want to keep your eyes on the road because you're very exposed (to danger)."*

**- Evaluation participant describing the vibro-tactile feedback
and how it relates to safety. (Translated from Swedish)**

When using PulsePath, some riders stated that they only used the visual feedback to confirm the instructions from the vibro-tactile feedback. Some riders even stated that they stopped using the screen almost entirely when using PulsePath.

"I think the most important thing was the alerts when something was happening. [...] When it vibrated, I instantly checked the map to confirm, even if I knew that I was supposed to turn right."
**- Evaluation participant describing the vibro-tactile alerts in
relation to the visual feedback. (Translated from Swedish)**

Regarding the encoding of the vibrations (section **8.1.2**), the participants had split opinions. Some participants felt the instructions were too complex as they primarily used them as an indication to consult the visual feedback, and some felt that the different alerts were intuitive. For some participants, the vibro-tactile feedback felt redundant in the sense that the *Far* signals came long before the actual navigation event and kept signalling until the navigation event was completed.

"I think it was quite confusing - especially when you're entering the roundabout there was way too much - there was so much going on. And if you are turning many times just behind each other - when we just left it was like "dwo dwo dwo dwo" [imitating intense vibrations] [...] Especially when you say it will be used in combination with visual feedback - i would rather have a notification - like 'hey watch out, something is going on, watch the screen.' I think it would work better for me to have a sort of reminder."
**- Evaluation participant describing the encoding of
vibro-tactile feedback.**

For roundabouts, the participants' opinions were once again split. Some felt that the vibro-tactile instructions for roundabouts were confusing, whereas some felt they were easy to understand. In regards to hardware, some participants stated that they did not feel when the vibrations went to both sides of the handlebar simultaneously, but that alerts that were supposed to be felt in both hands were only sensed in the right hand.

8

Results

In this chapter the artifact PuslsePath will be described in detail. PulsePath was the result of the pre-study and formative evaluations. Furthermore, research question 1 and 2 will be answered through the results and data gathered from the pre-study, formative evaluations and the summative evaluation.

8.1 PulsePath

In this section the final concept - *PulsePath* - resulting from the formative evaluation is presented. First, how the concept is envisioned to be integrated into the existing RGNT HMI is described. Second, the direction encoding is described and practical details on how it works in real scenarios are presented.

PulsePath was the concept used in the summative evaluation (see *chapter 7*). Reasoning and motivations for the different concepts underlying the design and design decisions can be found in previous sections of the chapter.

8.1.1 Integration with existing HMI

PulsePath is a haptic navigation instruction system that consists of two vibration motors that are mounted inside the handlebars of an electric motorcycle. Vibrations can be activated individually for each motor or simultaneously - producing vibrations into the motorcyclist's hands, either through only the left hand, right hand or both. The vibration motors produce patterns of vibrations that communicate ahead of time that a maneuver will soon need to be performed as well as communicate *when* the maneuver needs to be performed. The essential part of this concept lies in how the instructions are encoded, like "turn left" or "take the second exit on the roundabout," This encoding is at the heart of the concept's usefulness and value to users.

PulsePath is envisioned to work in conjunction with a visual navigation system. The system is thus not meant to guide the driver solely through haptic vibrations - but rather to work as an aid to minimize the amount of time and attention the driver has to direct towards a screen instead of the road and traffic situation. It's possible to receive and and correctly complete maneuvers without once confronting the screen on what to do with *PulsePath*. In more ambiguous or complex maneuver situations the vibration instructions provided by *PulsePath* can work as an aid to

help the driver quickly process the instructions on the screen.

Prototype abstraction   Note that the PulsePath prototype is an abstraction of this concept, where the visual navigation is not delivered through the RGNT HMI, but rather through a smartphone mounted on the handlebar. The hardware (i.e. the microcontroller, battery and circuiting) is also mounted externally, but is envisioned to be placed inside the motorcycle.

8.1.2   Vibration instruction encoding

To encode the maneuver instructions into vibration patterns that are comprehensible and given at the correct time a few concepts needs to be introduced. In the following section *ideal lead distance*, *alert levels*, *interstimulus interval* and *vibration patterns* are described and how they create the framework for the encoding of maneuvers. In this framework a *maneuver instruction*, or *instruction*, is the full set of communication sent to the driver, from the initial vibration until a completed maneuver by the driver. An *instruction* consists of multiple *alerts*, which are the individual vibration patterns sent to the driver over the course of the time period. A *maneuver* is the specific action the rider needs to perform - such as *'turn right'* or *'take the first exit in the roundabout'*.

Ideal lead distance

The concept of ideal lead distance is central to the concept of *PulsePath*. *Ideal lead distance* prescribes how far ahead before a maneuver should to be performed alerts needs to be given to a human driver. This is calculated through the lead distance formula based on the current speed of the motorcycle (see equation **6.1** in section **6.3**). Examples of different lead distances are given in the table below:

Speed	Lead distance
0 Km/h	21 meters
25 Km/h	51 meters
50 Km/h	81 meters
75 Km/h	111 meters
100 Km/h	141 meters

Table 8.1: Example of vehicle speed and the appropriate lead distance.

Alert level

PulsePath incrementally alerts the driver as they approach a maneuver. Initially it gently notifies the driver that a maneuver is coming up as well as what kind of maneuver. As the driver approaches the maneuver the intensity of the alerts increases, and finally it communicates that the action needs to be taken. These alerts

are divided into 3 levels for turn maneuvers - called *Far*, *Near*, and *Immediate*. For roundabouts these alerts are divided into 2 levels - *Far* and *Exit*. When these different alerts are given to the driver is based on the lead distance to the maneuver. See the table below:

Alert level	Lead distance zone
Far	4X
Near	2X
Immediate	1X
Exit (Roundabout)	2X

Table 8.2: The different alert levels and the corresponding lead distance they should be enabled in. *Far* should for instance be active until the vehicle is within the 2X of the lead distance, at which point only *Near* should be enabled

Interstimulus interval

Each alert is repeatedly sent to the driver every 3 seconds *or* every 15 meters. I.e. no alert is sent if the driver has not moved more than 15 meters even if 3 seconds has passed. The reason why an alert is sent every 3 seconds is to ensure that the driver doesn't miss an instruction due to vibration noise from the road or that they are not currently gripping the handle. The delay between signals is what called the *interstimulus interval (ISI)*. The ISI for left and right turns differs from roundabouts - this is due differences in the vibration patterns for encoding these maneuvers. It's possible for drivers to distinctly differentiate between the alerts for *near* and *immediate* patterns for turn maneuvers even when the arrive in direct succession due to a difference in vibration characteristics. The same does not hold for roundabouts - and thus alerts are never sent in direct succession for roundabouts.

The reason that the alert is not sent if the driver has not moved more than 15 meters is that in this scenario it's assumed that they are either stuck in traffic or for other reasons have stopped by the side of the road. To continuously send alerts in these situation would cause annoyance or simply be redundant.

ISI for turn maneuvers Once the driver enters the next alert level's ideal lead distance the next type of signal is immediately sent (see figure **8.1**). This is to ensure that instructions are given at correct time and not delayed in - which could cause the driver to have to react to abruptly or missing their maneuver. The *immediate* alert is only sent once, since that is when the maneuver is initiated by the driver and they do not need to be reminded of what maneuver to execute.

Figure 8.1: A visualisation of the *turn maneuver* ISI, where X is a multiple of the *ideal lead distance* from the navigation event and "Far", "Near" and "Immediate" relate to the different alert levels. The red dots represents when the alerts are sent to the driver.

ISI for roundabout maneuvers Roundabout exit alerts encodes numerical information into the vibration patterns. As this is the case, they can not be chained in immediate succession as that would the would produce an alert which is perceived as another instruction to the driver. I.e. if two "take the second (2) exit" where alerted to the driver in direct succession the driver would perceive it as the instruction "take the fourth (4) exit". Thus the ISI is always 3 seconds until the next alert is sent, and does not take into consideration if the driver has entered a new alert lead distance. This is visualised in *figure 8.2*. To ensure that an *exit* alert is sent before the ideal lead distance (i.e. 1X) has been reached the *exit* alert is initiated at 2X lead distance.
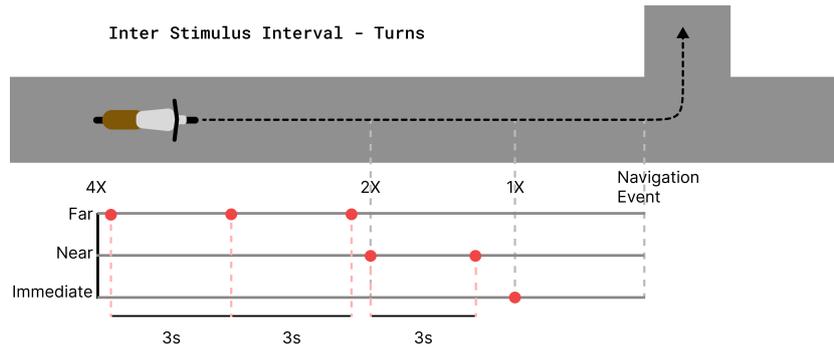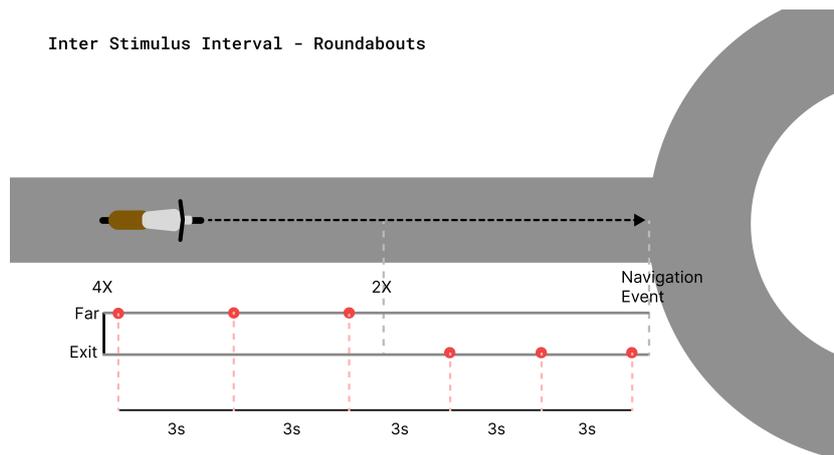

Figure 8.2: A visualisation of the *roundabout maneuver* ISI, where X is a multiple of the *ideal lead distance* from the navigation event and "Far" and "Exit" relate to the different alert levels. The red dots represents when the alerts are sent to the driver.

Vibration pattern

The vibration patterns communicate information to the driver of proximity to a maneuver (*Far, Near or Immediate*) as well as the type of maneuver - left turn, right turn or *n*th roundabout exit. This information allows the driver to plan their driving - placing themselves in the correct lane or position in the lane, adjust their speed, analyze the traffic situation and how it relates to the action that should be performed, and when to perform their maneuver. The vibration patterns differ between turns and roundabouts. A vibration pattern is created with the variables *pulse* - the duration for which the vibration motor is engaged, *interval* - how much time elapses between pulses and *repetitions* - the amount of pulses that are initiated.

Vibration pattern for turns   When approaching a right or a left turn alerts are only initiated in the corresponding handle - i.e. a left maneuver's instruction will only be felt in the left handle and vice versa. The vibration patterns are designed to be differentiable by the driver even if they occur in direct succession of each other. The details of the variables can be seen in table **8.3**, the pattern is also visualised in figure **8.3**.

Vibration pattern - turn	Far	Near	Immediate
Pulse (ms)	100	200	400
Interval (ms)	100	150	200
Repetitions	2	2	3
Total duration (ms)	300	550	1600

Table 8.3: Vibration pattern for turns - the pulse length and number of repetitions are increased as the driver approaches the maneuver.
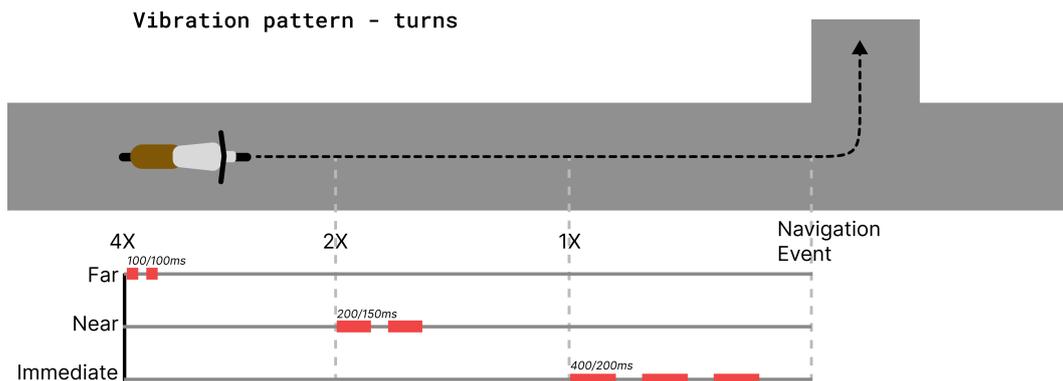
Figure 8.3: A visualisation of the *turn* vibration pattern. "Far", "Near" and "Immediate" relate to the different alert levels. The red lines represents duration for the vibration in the handle bars and amount of repetitions. Multiple "Far" patterns can for example be initiated before a "Near" pattern is initiated - depending on the lead distance zone the driver is in when the ISI has passed.

Vibration pattern for roundabouts For roundabout patterns, both handles vibrate simultaneously to communicate that the instruction regards a roundabout maneuver to the driver. When the driver approaches a roundabout they are initially notified that a roundabout is approaching with the *far* alerts. The *exit* vibration pattern encodes which exit number they should take through repetitions. E.g., for a pattern which communicates to take the first exit a single pulse is initiated, and for the third exit three (3) repetitions of the pulse occurs. The details of the variables can be seen in table **8.4**, the pattern is also visualised in figure **8.4**.

Roundabout	Far	Exit
Pulse (ms)	100	300
Interval (ms)	100	300
Repetitions	2	VAR
Total duration (ms)	300	VAR

Table 8.4: Vibration pattern for roundabouts. The amount of repetitions per signal correlates with the suggested exit. As an example, the third exit in a roundabout would be indicated by 3 repetitions.
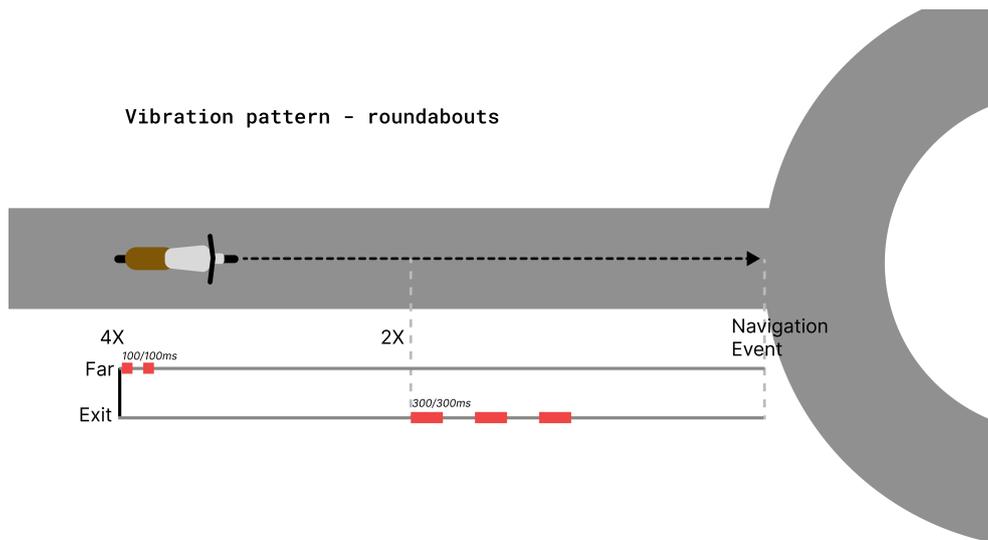
Figure 8.4: A visualisation of the *roundabout* vibration pattern. "Far", and "Exit" relate to the different alert levels. The red lines represents duration for the vibration in the handle bars and amount of repetitions. In this visualisation a "take the third exit" pattern is shown - which corresponds to 3 red pulse lines in the exit alert. Multiple "Far" patterns can for example be initiated before a "Near" pattern is initiated - depending on the lead distance zone the driver is in when the ISI has passed.

8.1.3 Scenarios

To better understand how *PulsePath* is experienced by the users during actual usage some scenarios will be described in the following section.

Multiple maneuvers in close succession   A reoccurring situation during navigation is when the driver has to navigate multiple turns in close succession. If that is the case, the driver will sometimes receive the next maneuver instruction immediately when they enter the next street. Sometimes the will be in the *near*-zone of alerts as soon as they enter the next street - if that is the case no *far* alert will be given to the driver for that maneuver instruction. This is visualised in figure **8.5**.
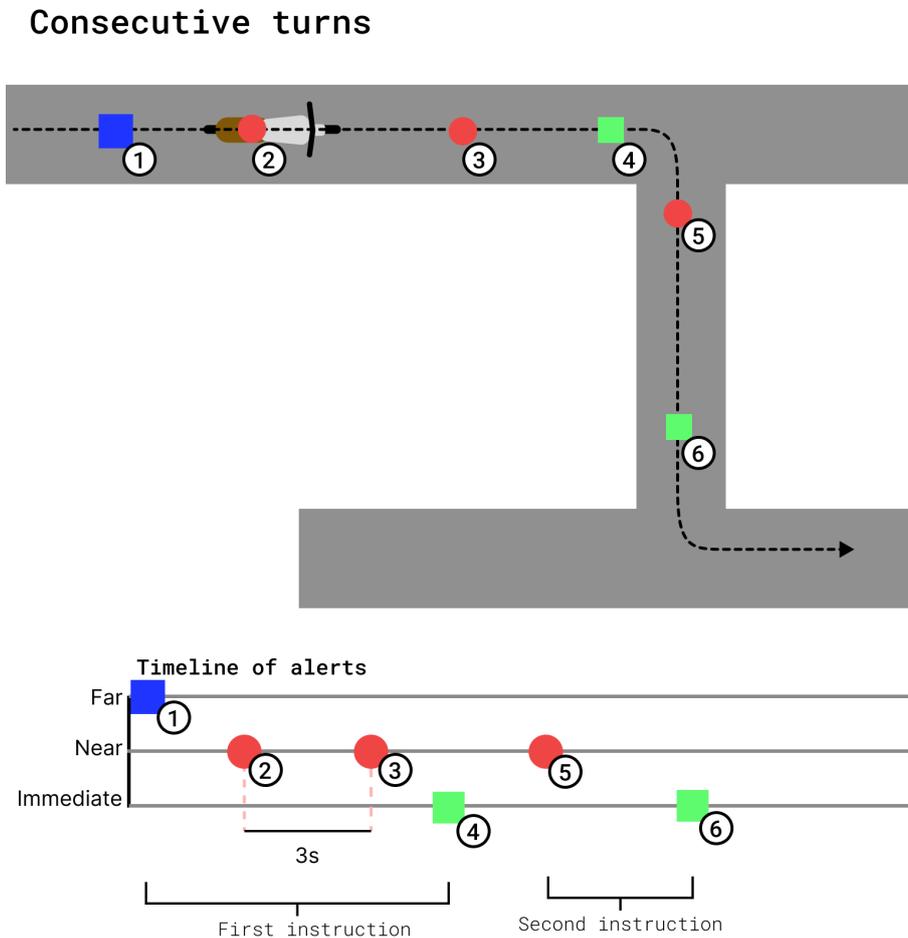
Figure 8.5: A visualisation of the scenario of what alerts are sent when a rider has to navigate multiple turns in a row. The first instruction is a right turn immediately followed by an instruction for a left turn. Each alert is numbered - and shown both where on the road the alert is given and presented on a timeline to show how they are consecutively initiated.

Ambiguous maneuvers   In city traffic situations it's not uncommon for multiple turns in the same direction to exist in close succession. When this is the case a driver who is unfamiliar with the time encoding of *PulsePath* might have difficulties choosing the correct street for the maneuver (See figure **8.6**). In this case it might be necessary for the driver to consult the visual navigation feedback to understand which street they are supposed to take. PulsePath still provides utility to the rider as they are *primed* - it calls their attention as well as already have provided general direction for the maneuver they need to perform. Less effort is needed from the driver to process the information on the screen since they already know what type of maneuver they are instructed to perform.
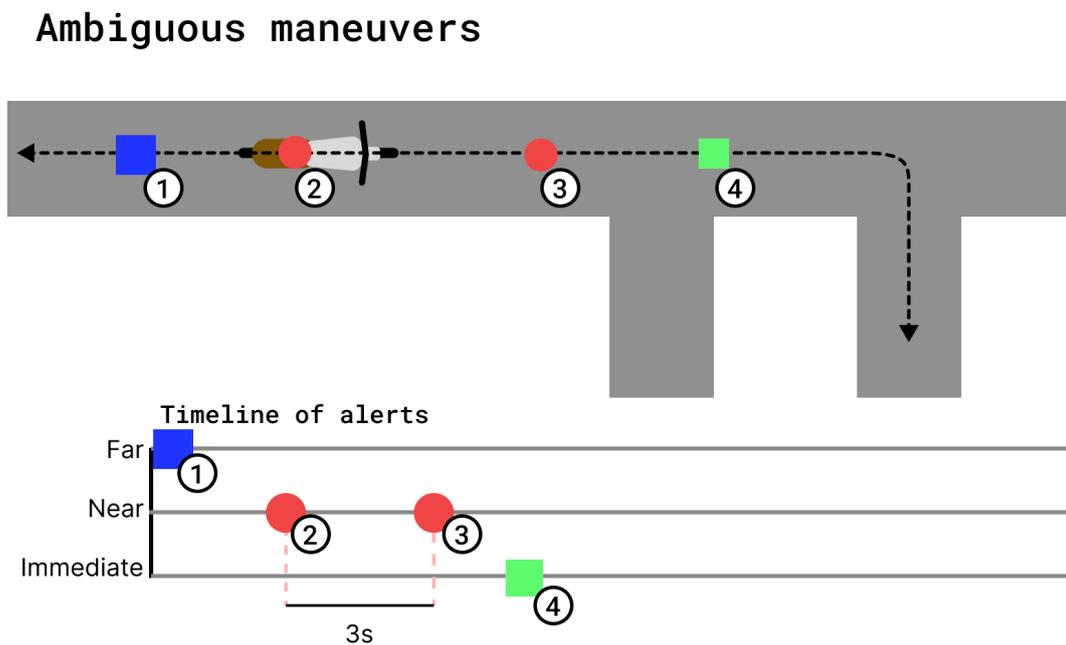
Figure 8.6: A visualisation of the scenario where the rider is supposed to take the second right turn available to them. Each alert is numbered - and shown both where on the road the alert is given and presented on a timeline to show how they are initiated.

8.2   Research Question 1

In this section the answer to the first research question will be answered:

> **RQ1***: "What aspects should be considered when designing integrated vibro-tactile navigation assistance?"*

The research question is answered as a collection of rider needs (section **8.2.1**), how these needs affect the design (section **8.2.2**) and how they relate to vibro-tactility

as a mode for navigation assistance (section **8.2.3**).

8.2.1 Rider needs

To understand how and why vibro-tactile feedback should be introduced into the context of e-motorcycling, the overarching goals for the rider needs to be well understood. From the pre-study interviews and the literature review, it became apparent that motorcycling could be well understood through the lens of Hassenzahl's *hedonic/pragmatic* model [5]. Motorcycling is a hedonic experience where sensation, thrill and identity allows the rider to express themselves and reach a state of flow. The hedonic aspects can however only be realised if the pragmatic aspects are in place - the rider needs to be able to reach their destination, to be safe while doing so, and that the vehicle handles according to the rider's actions.

The following three aspects where found to be of central importance when designing a navigation system intended for electric motorcycles:

Surroundings   - During the pre-study interviews all electric motorcyclist expressed the sentiment of being able to take in the surroundings as an important part of riding. This aspect of motorcycling was also found in previous research, as described in section **2.3**. This could mean enjoying the view whilst winding along a mountain road, appreciating a meadow with a herd of cows grazing it or driving into a city and have skyscrapers tower up above you. To be able to appreciate these things you need to be able to lift your focus away from the immediate driving situation for a little bit.

> *"... something that I really enjoy is slow cruises in country lanes where I can literally smell the forest and I can hear the birds singing as I cruise along [the road]."*
> **- Pre-study participant describing a pleasant motorcycling experience.**

Therefore, when introducing a product into the realm of electric motorcycling, one of its objectives should be to maximize drivers' ability to fully immerse themselves in and appreciate the surrounding environment as they traverse through it.

Riding   - Another need the participants expressed in the pre-study interviews was that of losing themselves in the experience of riding, i.e. becoming fully immersed in the task of controlling the motorcycle and experiencing the contact between the wheels and the road. This feeling can allow the rider to reach a state of *flow* where the motorcycle feels like it is an extension of oneself. It should be noted that "*riding*" in this case does not refer to the pragmatic aspects of handling the vehicle, but rather the hedonic and pleasurable sensations of the activity.

> *"I have to be in the moment, you can't be distracted. You have to be fully immersed in what's around you, which is kind of refreshing when you spend the day on a computer and you're being constantly distracted.*

And trying to do a million things at once, like the kind of the flow state
that you have to be in to ride a motorcycle well is appealing."
- Pre-study participant describing the allure of motorcycling.

This could be achieved through pushing the speed and handling to the edge of their ability for some riders, whereas others prefer to experience it through a more mindful approach - liking the experience to the calmer experience of sailing.

"I think it (electrical motorcycles) appeals to certain types of people. I
think people who prefer sailing over speedboats."
- Pre-study participant comparing combustion bikes to
electrical bikes.

A navigation product should thus aim too either enhance the experiential part of connecting to the motorcycle and road or minimize it's presence so the driver can focus on this connection.

Safety - The third, and arguably the most important, aspect needed to be taken into consideration when designing anything in the context of motorcycling is the *safety* of the motorcyclist. As a motorcyclist you are exposed to danger as soon as you venture out into the road, be it collisions with other vehicles or losing control of your motorcycle and crashing.

"The knowledge that I can be run over anytime is a constant."
- Pre-study participant discussing the dangers of motorcycling
in traffic.

Besides allowing the rider to appreciate their immediate surroundings, they also need the ability to perceive and react to dangers at a moment's notice. Keeping track of other vehicles, scanning the road for bumps or gravel and maneuvering the vehicle properly are activities needed to be performed simultaneously by the motorcyclist to ride safely. A product in the context of motorcycling should therefore be designed to help the motorcyclist operate their vehicle in a way that minimizes the risk of accidents - allowing them to focus on potential safety hazards. As stated in section **2.3.1**, interacting with a visual interface in-transit increases the risk of traffic accidents and should be avoided to keep the rider safe.

8.2.2   Impact on design

To satisfy the needs related to these three aspects - surrounding, riding, and safety - the designer should consider a few key points when creating a vibro-tactile navigation assistance interface. This in turn will maximize the hedonic and pragmatic user experience for the driver.

Streamline focus - If the rider does not need to constantly remind themselves to stay focused on acquiring navigational instructions, but instead are *notified* when to do so, they are able to focus on the motorcycling experience. They can let their

focus shift towards their *surroundings*, the *riding* and their *safety* - allowing their cognitive load to not be burdened by navigating at all until the system tells them to be.

Avoid annoyance - The system should not hinder the driver from appreciating their *surroundings* or the *riding*. A system which notifies too early, vibrates too intense or too often will cause annoyance for the driver. This was an issue that came up when participants described why they did not use audio-based navigation in the pre-study interviews. In the formative and summative evaluation some participants noted that the patterns and occurrences were "too much".

Individual differences - A number of participants in the summative evaluation were annoyed by the amount of information communicated through the handlebars and suggested that they should be tuned down. An equal amount of participants thought the communication arrived at proper time and with a good amount of repetitions. It's apparent that the amount of feedback needed to surpass into the threshold of annoyance for users was individual - and that there is no one-fits-all solution. Thus the system should be designed so that the user can adjust the amount of information delivered to their own needs.

Prioritize safety - All participants noted that *PulsePath* allowed them to have better focus on the cars and pedestrians around them when they were given navigational instructions in an additional domain to the visual. Aligning with the ideas of interface design for automotive and previous research examining occurrences for crashes, shifting your visual focus away from the road is the main source for potential danger. A navigational interface should be designed to minimize the need to avert your eyes from the road, and preferably not demand any visual attention at all.

8.2.3 Vibro-tactile navigation assistance

The rider needs and their impacts on the design of navigation assistance also relate to the design of *vibro-tactile navigation assistance* specifically. As the modus for receiving and interpreting haptic feedback differs from visual and audial, there are factors that are important to consider in this specific case.

Hardware - For integrated vibro-tactile navigation assistance to function properly, the rider must first be able to feel the vibrations from the navigation assistance system. Thus, the specific vibration motors need to be suitable for the product. Not only do they need to produce vibrations with sufficient power, they also need to work with the product they're integrated into. The designer needs to take vibrational noise from the vehicle and its contact with the road surface into consideration, as well as the type of handlebar. As was found in the creation of PulsePath, more specifically during iteration of the vibration motors' placement (section **6.4.5**), some handlebars might propagate the vibrations in a way that makes interpreting the source of the vibration impossible. Also, it was noted that the vibrations were hard to discern when riding on cobblestone-paved roads, as the vibrational noise

from the surface was too high. Without proper selection of vibration motors and placement, all other design implementations become irrelevant.

Encoding - With proper encoding of the vibro-tactile navigation assistance feedback, the rider is able to understand the signals and translate them to physical actions intuitively. If the rider can use and understand the system without excessive cognitive workload and frustration, it makes for a more pleasurable and safe riding experience.

The motorcyclist needs to know what action they are supposed to take (i.e. "turn left" or "take the third exit of a roundabout"). In this thesis effort was put into the design of the *vibration patterns* (section **6.4.2**), with the result being distinguishable signals correlating to specific actions. The vibration patterns used in this thesis allow the rider to easily understand the navigation instructions, as each alert level (i.e. far, near or immediate) had different patterns. By making sure the rider understands the haptic instructions, PulsePath allows them to lift their gaze and *focus on traffic* without having to consult a visual navigation interface. Designing discernible haptic navigation instructions is a way to *avoid annoyance* for the rider, as an understandable encoding decreases the cognitive workload needed for navigation.

Timing - Not only does the rider need to understand what action to perform, they also need to know *when* to perform it. Proper timing is necessary to produce a satisfactory motorcycling experience - if the rider is alerted too early the haptic instruction become annoying, if they're alerted too late they might not have time to position themselves correctly and miss their turn. The timing does also need to be *consistent* in order to ensure that the rider can understand and trust the instructions given to them.

In this thesis, the timing for the haptic instructions was considered in two aspects - distance and inter-stimulus interval (ISI). The appropriate distance from rider to navigation event to send navigation instructions was calculated using the current riding speed (section **8.1.2**), as a fixed distance for the timing would only work at fixed speeds - it takes less time to traverse 100 meters when you're riding at 80 km/h than it does at 30 km/h. In conjunction with the encoding, the ISI (section **6.4.3**) used in the PulsePath prototype provided *consistency*. As the vibration patterns differed between alert levels, it allowed us to use a dynamic ISI allowing for instructions to be consistently sent at the appropriate time for navigation events at all speeds.

Context - When designing a vibro-tactile navigation assistance interface, it is important to be mindful of the context. When used together with a visual interface, the purpose of the haptic feedback could be to catch the rider's attention and instruct them to consult the screen for navigation instructions. In a stand-alone vibro-tactile navigation assistance interface, the encoding needs to be more complex in order to

allow the rider to understand the instructions.

In this thesis, the interface was designed to function on its own as well as together with a visual interface. During evaluation, it became apparent that different riders used PulsePath in different ways. Some participants used it as an alert to consult the visual navigation assistance, whereas some only used the vibrations for instructions. Therefore, it is important to not only considered the different channels for feedback, but also the *individual differences* between users.

8.3 Research Question 2

In this section, the second research question is answered:

> **RQ2***: "How does using the vibro-tactile navigation assistance feedback provided by PulsePath affect the riding experience?"*

This question was explored through the development and evaluation of the *PulsePath* prototype. In this section the data collected from the summative evaluation is interpreted to answer the question.

8.3.1 Performance

When using PulsePath to navigate a route on an electric motorcycle, no substantial change in vehicle performance was found. Data on objective performance measures showed that users did not decelerate their bikes much differently (-0.4%) with the added feedback (section **7.5.1**), as well as an indication that they made less navigation errors (section **7.5.2**). However, the findings from the evaluation also mean that the vibro-tactile navigation assistance doesn't affect vehicle performance *negatively.* The low impact on braking performance and the indication of fewer navigation errors are testaments to PulsePath being *effective* in the sense that it delivers perceivable and understandable navigation instructions in good time. If it was not, it is likely that the evaluation would have shown an increase in both the percentage of hard braking and navigation errors.

8.3.2 Workload

The PulsePath evaluation showed that adding vibro-tactile feedback to the motor-cycling experience lowered the workload demanded from the participants (section **4.11.3**). The NASA-TLX aspects of *Frustration* and *Mental workload* were notice-ably reduced when the rider received instructions through vibro-tactile feedback. This could be explained by a combination of reasons:

Reminds the rider to focus on the navigation - The vibro-tactile feedback alerts the rider when it's time to focus on taking a turn or performing another maneuver. This means that when no instructions are received the rider can stay focused on other aspects of the motorcycling experience - the rider doesn't constantly

have to remind themselves to focus on navigation. In the post-ride interviews one participant said *"With vibrotactile feedback, you don't look [at the screen] 1km or 500m away but when something actually happens."* (translated from Swedish). This indicates that the timing of the vibro-tactile navigation feedback was satisfactory and that the encoding was effective.

Allows drivers to lift their gaze - Since the vibro-tactile instructions tells the rider which maneuver to perform they don't have to consult the screen when the action is approached. Their vision can instead be used to read traffic and road conditions. When drivers do not have to alternate between reading traffic and reading the screen the mental workload is lowered. One participant said that *"Navigation with a vibrating handle - it kept my eyes on the traffic instead of looking elsewhere (the screen). Made me feel much safer."*, supporting the theory that vibro-tactile navigation assistance makes motorcycling feel safer due to lower visual demand.

8.3.3 User experience

In terms of the pragmatic and hedonic qualities of user experience as per Hassenzahl [5], PulsePath provided a better user experience when compared to using only the visual navigation assistance (section **7.5.4**). Using PulsePath allowed the riders to focus more on the hedonic aspects of motorcycling - the joy of riding and taking in the surroundings. In the post-evaluation interviews, one participant stated: *"Riding with the vibrations made me feel like me and the bike were a single unit - otherwise it felt like it was me against the bike, or me and the bike. It felt inclusive in some way."* (translated from Swedish). PulsePath also made the motorcycling feel safer, much because it allows the rider to put visual focus where it matters - i.e. the immediate traffic situation.

In the post-evaluation interviews, some participants expressed that the vibro-tactile feedback felt annoying at times as there was too much information coming from the handlebars. At the same time, other participants felt the encoding and delivery to be just right for them to navigate according to the instructions. This once again ties back to the fact that a one-size-fits-all solution does not exist, and that an implementation of PulsePath should have some way for the rider to adjust the information according to their needs.

Most of the participants in the evaluation had no experience with the PulsePath prototype. Nonetheless, after a short introduction to the system they were all able to understand the instructions and react accordingly - strongly suggesting that vibrotactile instructions are effective and easy to learn. In the results from the AttrakDiff3 questionnaire (figure **7.8**), the only word-pair that breaks away from the pattern is *undemanding-challenging* with a higher score for *undemanding*, further indicating that PulsePath felt easy to use to the participants. The intuitiveness and learnability of PulsePath aligns with human factors research in the domain where the spatial information of a vibrational stimuli is effortlessly converted into a direction

(section **3.1**). This intuitiveness hold true specifically for left- and right-turns were every evaluation participant thought it was easy to understand. The more complex roundabout instructions were considered intuitive to most participants - although a few participants thought the instructions were a bit confusing, with the caveat that they would probably more easily understand with more usage. We claim that vibro-tactile navigation intuitively extends the driving experience.

9

Discussion

In this chapter limitations, potential ethic issues and suggestions for future work are presented.

9.1 Study limitations

In this section limitations with the design process and evaluation are presented as how they affected the PulsePath prototype and their impact on the results.

9.1.1 Evaluation

The study was limited to recruit participants within the company of RGNT. This was mainly due to insurance reasons, as non-employees would not be insured when participating in the evaluation. Furthermore, the motorcycle used for evaluation was only available for 2 weeks before it had to be used for other projects within the company. When the open invite was sent out, employees had to fit the evaluation test into their work day. Those working in the Research-and-Development(RnD) department, where the thesis was conducted, could find time for the task within the context of their work duties whereas other departments could not. This meant that the participants were mainly from the same department as the thesis had been conducted (n = 8). This could have influenced the following aspects of the evaluation results:

Population size - The amount of participants was rather small (n = 10), which had implications when analysing data, decreasing the significance of findings. This was mitigated by using Wilcoxon signed-ranked tests where applicable, as the method does not assume normal distribution. However, the low amount of participants meant that each individual participant had high impact on the test results.

Selection bias - The selection of participants was not random, and might not generalize to a broader population.

Demand bias - The participants of the study had incentives to provide results that were in favor for the PulsePath prototype. Participants knew the study conductors and the project well after working along each other for 3 months. Furthermore, as most participants came from the RnD department, it is reasonable to assume

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that they have an interest in novel technologies and their implementation - furthering their inclination to answer positively in the questionnaires and post-evaluation interviews.

The constraints of the participants also influenced and limited the study design. Since the participants had to take time out of their workday the study was designed to take the minimal amount of time. This meant that no motorways were included into the routes as that significantly extended the testing times when designing the routes. The data gathering during the evaluation was also affected. The NASA-tlx was changed to a raw NASA-tlx to minimize the test time. Post-test interviews were as limited in scope as possible to save time for the participants. This in turn resulted in the evaluation not being able to answer how the prototype was experienced at very high speeds (>100 km/h). Furthermore, qualitative findings into details of things such as "How it affected the handling of the bike", "Detailed descriptions of how the instructions for different maneuvers was perceived", could thus not be explored. Excluding the weighting process from the NASA-tlx mean that each construct influenced the final score equally. Our hypothesis is that physical workload has a much lower impact on the actual workload experienced when navigating than the other constructs, but such intricacies are lost when utilizing the raw NASA-tlx variation.

9.1.2   Evaluation metrics

As visual distraction is a major factor for both mental workload and the risk of accidents (section **2.3.1**), difference in the amounts and duration of screen glances between the two feedback modes (PulsePath and visual-only) would have been a good measurement for the vibro-tactile navigation feedback's impact on riding performance and workload. However, the technology and knowledge to implement such a measurement was not possible to achieve within the time span of the project. Instead, we opted for measuring the percentage of hard braking as per Harbluk et al. [84]. This metric might not be indicative of the different feedback modes' impact on vehicle control, as the same difference of 0.4% was found when analyzing the different routes' impact on the percentage of hard braking. We also found that the percentage of hard braking differed between participants, indicating that it has more to do with personal riding style than mode of navigation assistance feedback. Further, a high percentage of hard braking could be indicative of a skilled rider as it is shows the ability to brake hard without losing control of the vehicle. Thus, the claim that PulsePath has low impact on vehicle control could be considered a stretch, as there are more aspects that defines what *vehicle control* is other than the percentage of hard braking.

9.1.3   Prototype

When creating the prototype, three different pairs of vibration motors were available. Out of these three, only two could fit in the handlebars and one pair broke during soldering. The effect of this is that we had no choice of vibration motors,

which in turn entails that the motors used in evaluation might not have been optimal for the prototype. However, the vibration motors used provided sufficient power for the vibrations to be felt by the participants - contributing to the functionality of the PulsePath prototype.

For some reason, supposedly because of poor fitting of the vibration motors into their 3D-printed casings, the left vibration motor was hard to distinguish when both motors were activated. The extent of how the difference in vibration perception affected the evaluation is hard to gauge, but it might have been the cause for some participants misinterpreting roundabout instructions as right-turn instructions. When only the left vibration was activated however, the vibration pattern was distinguishable.

During the summative evaluation a few of the participants commented on visual navigation part of the prototype. It was said that it was 'too zoomed in' which made it difficult to see ahead where the next navigation maneuver would occur, furthermore it was perceived to have a delay between real world location and where the location marked on the screen. Since the same visual navigation was used for both modes the evaluation results hold internal validity. However, a more refined visual navigation would have been more representative of a baseline visual navigation system.

9.1.4 Process

During the formative evaluation of the PulsePath prototype, the participants used the vibro-tactile navigation assistance as a stand-alone product. In the summative evaluation however, PulsePath was used in conjunction with visual feedback. This may have been the cause for some participants expressing that the encoding felt "over-engineered" and annoying and that they mainly used the vibrations as an instruction to consult the visual feedback for navigation assistance.

The dissonance between the design of the prototype in formative and summative evaluation was not only detrimental. Designing for stand-alone vibro-tactile feedback brought with it effort put into understanding the importance of encoding the feedback, and the final prototype illuminated the importance of context.

9.2 Potential ethical issues

Although the results from this study indicate that using vibro-tactile navigation assistance increases the safety of the rider, we have no actual data supporting this claim. If PulsePath would be made available to the public, claiming that it makes motorcycling safe could lead to a sense of false security.

9.3 Social impact

As integrated vibro-tactile navigation assistance only is feasible in non-combustion powered motorcycles, it could make electric motorcycles more attractive to the consumer. As there are no harmful exhausts emanating from an electric motorcycle, the riding does not contribute to pollution. However, producing electric motorcycles is hard to do without producing carbon dioxide and mining precious metals. Thus, claiming that more electric motorcycles would have a positive environmental impact would be bold and akin to green-washing.

Using PulsePath assist the rider to focus their vision on their immediate traffic situation, possibly making for a safer riding experience and in extension decreasing the amount of traffic accidents. Claiming that PulsePath would make the roads safer is however another bold claim as motorcycling is inherently dangerous, and the best way to not get into a motorcycling accident is to not get on a motorcycle in the first place.

9.4 Future work

While this thesis has explored and provided insights into the research problem at hand, there are several avenues for future work that can further advance the field and build upon the findings of this study. This section outlines potential directions for future research.

High speed and city navigation - Since PulsePath was never used on motorways no conclusion about it's usability could be drawn from this study for this context. Although no evidence suggests that there would any substantial difference, further work would need to be done to ensure that this is the case. The increased vibration noise at high speeds could potentially make the instructions indiscernible.

In the evaluation, multiple low-speed turns were produced by guiding the participants through a residential area in Kungsbacka. It would be of interest to explore how well PulsePath works in more densely populated cities with a higher amount of traffic.

Adjustable levels - The summative evaluation highlighted how some experienced the amount of alerts, vibration patterns, and ISI as annoying in the PulsePath prototype. To explore the least needed amount of instruction needed to be able to correctly and reliably navigate would be a logical domain to explore in future work. To understand if the system only needs to alert the user to look at the screen to receive navigation instructions or if the maneuvers should be encoded in a less intrusive way.

Other information - At the start of the project, a project of integrating vibration motors for communicating turn indicator status had been started at RGNT. As it turned out, participants forgetting that the turn indicators were activated was a common observation made during the summative evaluation. As the information provided from the vibration motors is quite abstract, exploring what information could be included in the vibro-tactile system and how to encode it to be differentiable would be an interesting route for further development of PulsePath. For instance, road condition and warnings as well as system vitals could be information relayed through vibro-tactile feedback.

Long-term UX - In this thesis, the evaluation only consisted of two trips of 20 minutes. The results showed that PulsePath was easy to learn and added to a positive motorcycling experience. Releasing the product to consumers in a longitudinal study could provide understanding of the *long-term UX* related to PulsePath, and how it feels to use the product for longer timespans than 20 minutes and with real-world scenarios.

Comparative evaluation of encoding schemes - To establish which vibration encoding scheme is preferable, a comparative evaluation can be conducted between the encoding scheme used in the PulsePath prototype and the encoding schemes of HaptiMoto [36] and MOVING [37]. By evaluating the effectiveness, user preference, and usability of each encoding scheme, valuable insights can be gained to guide the development of future vibro-tactile navigation systems. This evaluation should consider factors such as accuracy of instructions, ease of understanding, user satisfaction, and overall system performance.

Generalizability to other contexts - The applicability of PulsePath extends beyond electric motorcycle navigation with a visual interface. Exploring its effectiveness in contexts such as delivery driving, bicycling, or vehicles without screens would broaden its reach and impact. Conducting empirical studies and user evaluations in these contexts would assess PulsePath's usability and compare it to traditional visual navigation systems. This research would contribute to understanding its potential benefits and facilitate its integration in diverse real-world scenarios.

Thorough Evaluation - As stated in section **9.1.1**, the amount and selection of participants in the evaluation for this prototype was severely limited. To produce results that hold stronger ecological and external validity, a more extensive and diverse participant pool should be considered for future evaluations.

10
Conclusion

The starting point for this thesis was the question *"What is the future of navigation"* in the context of electric motorcycle. RGNT motorcycles, a company which designs and produces electrical motorcycles, was the stakeholder who provided this initial prompt. In order to gain an understanding of the ambiguous initial inquiry it needed to be refined and specified further. This was done through consultation of previously conducted literature, artefact motorcycle research and qualititave interviews (n = 8) with riders of electrical motorcycles. Through this investigation the overarching goals for motorcyclist were discovered - as in, what is enjoyable about motorcycling and what practical aspects are important. This was condensed in to three main aspects or system goals: To be able to take in and experience the *surroundings* you are riding in, *Riding* the motorcycle in a way where the handling of the bike puts you in a state of flow and the need to *safely* be able to keep track of vehicles and other hazards on the road to avoid accidents.

Previous literature and proof-of-concepts developed at RGNT guided the thesis to explore how these system goals could be met through multi-modal navigational instructions - more specifically through the use of vibro-tactile feedback. Previous artefact research had successfully showed that navigational instructions can be provided through vibro-tactile feedback in the context of combustion-powered motorcycles. In this context, the vibrational noise generated from the motorcycle entailed that the vibrations had to be provided through peripheral devices. Thus, the goals was to explore if and how vibro-tactile feedback could be *integrated* into an electric motorcycle as they do not produce as much vibrational noise as their combustion-powered counterparts. This provided both new scientific knowledge and value to RGNT as a company.

The initial study was condensed into two research questions, presented below:

> **RQ1**: *"What aspects should be considered when designing integrated vibro-tactile navigation assistance?"*

> **RQ2**: *"How does using the vibro-tactile navigation assistance feedback provided by PulsePath affect the riding experience?"*

To explore the domain of electric motorcycling and answer the research questions, a prototype named "PulsePath" was developed to provide vibro-tactile navigation assistance feedback, which was integrated into the handlebars of an electric motorcycle. PulsePath consists of a pair of vibration motors and a microcontroller,

connected via Bluetooth to a visual navigation smartphone application. An iterative design process was employed, involving formative evaluations with the prototype and motorcyclists, to determine effective encoding of information. These evaluations focused on understanding vibration patterns, timing intervals between vibrations, and appropriate alerting mechanisms for riders, ensuring comprehensible instructions without causing annoyance. The insights from these formative evaluations facilitated the establishment of a framework for designing a vibro-tactile navigational system. Furthermore, the completed PulsePath prototype was used in a summative evaluation for understanding how it affected the motorcycling experience.

The formative evaluation identified important aspects for designing a vibro-tactile navigation assistance. The research addressed rider needs, including appreciating their surroundings, immersion of the motorcycling and safety. These needs guided the design, focusing on streamlining rider concentration, avoiding interference with the hedonic aspects of motorcycling, accounting for individual differences, and prioritizing traffic safety. Regarding vibro-tactile feedback, key considerations included selecting suitable hardware, encoding understandable feedback, timing cues, and understanding the contextual factors such as available feedback channels, personal preferences, and road types.

The results of the summative evaluation showed that using PulsePath had no substantial impact, negative or positive, on vehicle control when measured with the percentage of hard braking. In terms of *effectiveness*, there was an indication that the participants could navigate more easily when using vibro-tactile feedback in comparison to using only visual feedback. The raw NASA-TLX questionnaire revealed an overall decrease in workload, most significant in the aspects of *frustration* and *mental workload*. The AttrakDiff3 questionnaire and post-evaluation interviews showed positive results in favor of vibro-tactile feedback. Using PulsePath allowed the participants to focus on the pleasurable aspects of motorcycling, as well as making them feel safer in traffic since the vibro-tactile feedback allowed them to focus their vision on the immediate traffic situation.

This thesis builds upon previous research and provides new insights into the domain of vibro-tactile navigation systems for motorcycles. Knowledge of how such a system can be implemented into an electrical motorcycle has been generated through the use of a user-centered design approach. This knowledge has been used to answer the research questions and can be used in further research in the domain of in-transit human-computer interaction.

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A

Appendix A

From the 4 interview conducted with drivers of EV-motorcycles six broad categories of interest where discovered:

Real time navigation information

What the system communicated and how it communicated the information to the rider from moment to moment was a recurring topic. Multiple aspects of the real time information were discussed and presented. When asked what hedonic benefits the navigation brought to the drivers, they meant that the fact that they could just let the navigation guide them correctly meant they could relax and focus on the driving. The navigational assistance was perceived as **lightening the cognitive load** of the drivers as they could direct their focus elsewhere.

Using audio navigation

2 of 4 riders used audio navigation as their main modality for receiving turn-by-turn directions in real time. The ability to fully focus with their eyes on the road and have the NavAss communicate through audio into the helmet allowed them to stay more alert on traffic, but also made the ride more pleasurable as they could experience their surroundings more fully. They either put the phone in their pocket and only utilized the audio prompts, or had a phone screen mounted on their handlebar and combined both auditory and visual information. In the latter case the audio was the main source for directions and the screen was only occasionally consulted/glanced at to better understand the auditory information.

Learn to understand auditory directions

3 riders expressed issues where the ambiguity of the audio-based directions meant that the experience was hindered or lessened.
For example, multiple turns to the right in a short span of road, where the audio only prompts you to *"take the next turn"* mean that it was uncertain which road the spoken directions meant. Which in turn meant that drivers turned too early or too late.
One rider stressed that it was just a learning curve to these kinds of directions and that once you've learned how the system conveys this information it wasn't a big problem.
For other drivers this ambiguity meant that they had "given up" on audio-based directions and mainly used screen based navigation instead.

For one rider, they expressed issues with information in specific situations on roads with multiple lanes. EG. if there were 4 lanes and you needed to place yourself in the leftmost one, no such information was conveyed through audio (Gmaps).

Resolution of information

The users who mainly used audio-based directions for their navigation stressed the need to be able to adjust how much information was conveyed to the driver and it should adapt to the current context. Too much spoken information when not needed was ***annoying*** and **distracting**. Furthermore, directions that felt obvious or unnecessary were perceived as condescending. Being told to do what you are already doing should be avoided.

One interviewee suggested the functionality of partitioning your ride into segments, in which the directions were less and more elaborate. They explained that they might want to go to a

location in the southern parts of the city, a general direction which they are familiar with and can locate on their own, but once they are in the vicinity of their destination, say a hardware store, they might need much more concrete and direct information to end up on the specific street they are interested in.

Minimizing distraction

Touched upon above, the need for the system to minimize distractions, both visually and information wise is essential. For the Google Maps-based driver, they perceived spoken navigation as too distracting and were not using it for that reason. whereas the other drivers perceived the visual map as too distracting and avoided it for that reason. Overload of information through any channel, drawing focus from driving should be avoided. It seems that the modality of information is preferential and different between users. So a Navigational system must accommodate both of these channels.

One driver talked about reading street names as part of navigation and how that was very distracting, as they needed to move focus away from the road in order to read.

Turn-by-turn resolution

In moment-to-moment driving a few points were brought up regarding real time information. Precise information in meters on when to turn (EG *"turn in 50 meters")*, was stressed by all drivers to be important. This could either be conveyed through audio or the driver collects that information by looking at the map and asses how far their "avatar" is from the turn.

Visual information communication

One suggestion was a countdown bar, similar to a download progress bar, that "counted down" until it was time to turn, which could aid visually. Interest in "low-res" information was expressed by 2 drivers, similar to the Beeline, where simple arrows or direction "suggestions" seemed enticing to the drivers as a way to minimize information whilst retaining usefulness.

Including house numbers as part an aid for the drivers to localize themselves were also brought up by one driver.

The sensation of riding

Appeal of operating e-motorcycles

Some riders expressed an appreciation for the **simplicity** and the amount of **control** they felt over the e-motorcycles in relation to combustion motorcycles, where the accessibility and instant delivery of the motorcycle's torque and power was appreciated. One rider also went into detail about the regenerative braking (of an energica eva ribelle) and how the braking system (tilt "throttle" handle forward for regen) opened up a new and pleasurable way of riding.

Exciting rides

In relation to the mechanical appeal of e-motorcycles, some riders described what they find exciting about e-motorcycling. One rider talked about the joy of pulling away quickly from a standing start at a red light, another about using their energica's regenerative braking to perfection on fast, winding roads and another about the state of focus e-motorcycling demands of the rider.

Pleasant rides

Nearly all riders described, in some way or another, more **pleasant** aspects of riding rather than exciting. Two riders mentioned the silence that comes with an electric motorcycle - and with it idyllic summer rides where you can hear birds singing. Also mentioned was the freedom of motorcycling, and one rider made the analogy that sail boats vs speed boats resembles e-motorcycles vs combustion - where sail boats and e-motorcycles are more sophisticated and refined compared to the loud expression of power found in combustion engines. The silence of e-motorcycles was also mentioned in the context of longer trips, as a factor that allows for more pleasant longer rides as there is less grating noise.

Practical rides

Besides exciting and pleasant rides, all riders interviewed used their e-mcs for practical uses like running errands and commuting. For the riders living in big cities, the ability to commute smoothly and quickly, in comparison to commuting by car or public transport, was an attractive factor. They also mentioned that commuting by e-mc is **more fun** than by car or public transport. Sadly, we did not probe more in-depth about what's fun about e-mc commuting. One of the riders mentioned that it goes both ways - sometimes running an errand is an excuse for a motorcycle ride.

Motorcycling in traffic

One enjoyable aspect of e-motorcycling was the ability to weave or filter between cars in traffic, although this seemed to not always be appreciated by other road users as one rider stated that it felt like cars sometimes tried to ram them as an act of aggression. The ability to opt out from queueing made riders feel like they **made correct choices**, and the stationary vehicles they pass on their rides became a confirmation of that feeling.

Unpleasant rides

When it comes to the negative aspects of e-motorcycling, it seemed like they were all external factors. Many riders brought up the dangers of traffic in the context of motorcycling,

that cars sometimes didn't see the riders and a collision could be dangerous for the rider. Also mentioned were road conditions (gravel in curves) and slippery roads due to bad weather.

Besides frightening and dangerous rides, the riders also talked about *boring* rides - mainly in the context of riding on motor- or highways. When talking about filter options in trip planning, two riders mentioned filtering out motor/highways. Bad weather was also mentioned as an annoyance factor.

Interestingly, when asked about the negative aspects of e-motorcycling, no rider mentioned range limits. It seems that even if the limited range is a factor, it is not a factor that is hard to handle. One rider mentioned that any additional detour is made with the range in mind, and is carried out as long as the battery allows it.

Charging stops

The two riders that had used their e-mcs for day trips and touring spoke about the charging stops in a positive manner. For them, the charging stops were a chance to take a break from riding, and sometimes explore surroundings they otherwise wouldn't be in. The rhythm the charging stops impose on the trips was seen as a positive, whereas a fuel stop for a combustion motorcycle could lead to a more tiring trip.

Trip planning

One central part of navigation is planning the trip. Setting the destination, to understand how long it will take to arrive and how far away the destination is.

When do riders trip-plan

One rider described that they usually bring up their phone and input their destination as they are walking to the bike, if the bike has a screen they expect it to sync up (bluetooth) and show the navigation on the screen once they start the ignition. Immediately being "thrown into navigation".

Another approach was given by a rider which looks up their destination sometime earlier in the day, checking time to arrival and so forth either on their PC or their phone. Once they get to their motorcycle they bring up their navigation app and retrieve the trip from the "previous" or "history" page. The same rider also talked about if they were late to their destination that they jumped on their bike and put in their trip at the next red light.

Trip planning in practice

One rider said they ride from one destination to the other if they have several stops they want to visit during a trip. They input each new destination once they are "finished" with their current stop. They did not "chain" the destinations into one continuous session, a function that is available in Google Maps. Similarly, when another rider was asked if they utilize the "chaining" function they were confused and probably not even aware that the function exists.

One rider was highly interested in the ability to adjust what "kind" of ride the navigation assistance gave them, exemplifying with ideas such as "most economical", "fastest", "closest". Another user gave the suggestion for a similar function adding ideas such as "curviest road", "quietest". This functionality can be found in services like Calimoto.

One interviewee asked for the functionality to control the route during the planning stage to force it to go along a certain route or specific location. Their intention with this functionality was to go along the top of a mountain or along winding routes they knew about.

Trip Planning and charging stations

2 of the users stressed the importance of being able to see the available charging stops along the route that is being planned, even those not in direct connection to the road they are traveling on. A suggestion was a "button" that could be pressed to directly navigate to the closest charging station. This all seems to indicate the importance of charging for the riders, especially those who use their e-mcs for longer trips.

On the contrary, the other 2 drivers did not mention charging stations. Since they charged their bikes at home overnight, their bikes were fully charged by the morning and could take them through all the driving of the day. This indicates that there really is not a high need to have knowledge of charging stops for riders who use their e-mc for commuting.

As discussed in the moment-to-moment navigation section, the possibility to adjust how much information is delivered to drivers based on their proximity to their destination was brought up by all 3 drivers who regularly use navigation assistance.

They all expressed a need to be able to adjust when the navigation assistance "kicks in", and only give directions when you are so close that you need it. If you know the general location and how to get there, you don't need assistance until you arrive in the "general location".

Aesthetics

To have an interface that is dated or rather "feels dated" is an issue that was brought up by one user. *"When I fall back on the cars (year model 2014) inbuilt navigation, it feels older than 10 years.".* They stressed the fact that a UI that is not continuously updated to the latest look will feel old is a detriment to the experience.

Another user was critical towards *WAZE*s cartoony look and said that they had stopped using it even though it provided great functionality, indicating that the identity one is trying to express when using their motorbike has to be aligned with the interface "style". The same user commented on the stylized voices that some systems use to deliver their turn guidance with (Samuel L Jackson) and how it "could be fun for some but not for me", further indicating the need for aesthetics that fit the rider.

Identity

Smartphone Aversion
When asked about positive aspects of motorcycling, two riders in particular mentioned the act of riding as a way to get a break from screen-based activities. In relation to the riders' appreciation of the simplicity and control of electric motorcycles, connecting one or several smartphone apps to the riding experience seemed to be more of an annoyance than a convenience. For one rider, motorcycling seemed to be about disconnecting from the digital world and enjoying the connection with nature.

Interaction with other people
Two of the four riders had positive accounts of interacting with other people where their electric motorcycle had been the source of interaction - "What a cool bike, is it electric?". Riding the electric motorcycle through tourist-heavy sections of the city was mentioned as an appreciated type of ride. One rider touched on the subject of **being an early adopter** as a positive aspect. 2 of the riders used words such as "cool" when describing their interaction with others, indicating some sort of need to **impress** as part of the identity building.

Interaction with other riders & friends
To use the connectivity of a smartphone and/or an internet-connected motorcycle to communicate with other riders was mentioned as an attractive field of development for some of the riders. Being able to see others' locations while group riding and game-like geocaching activities were some of the ideas from the riders.

Smartphone integration

The riders all accounted for using smartphones as a tool for navigation assistance. Some used phone holders attached to their bikes, while others put their phone in their pocket while riding.

Phone holders

The riders that used phone holders expressed some extent of worry regarding safety. Neither used the magnetic types, as the risk of the phone coming loose at high speeds felt too high. There were also qualms of the phone holder being detrimental to the motorcycles aesthetics, particularly mentioned while talking about a RGNT classic. One rider mentioned that one of their old bikes, a BMW C400X, had no place for a phone mount and that the rider then had to use the sub-optimal built-in navigation.

Phone battery

A rider that used their bike for day trips, and perhaps the one that used navigation assistance the most of the four, mentioned that they had mounted a USB cable with wire clamps to supply their phone with electricity while riding. They also mentioned *Magic Earth* as their favorite navigation app, in part due to the fact that the app displayed battery status while in use - something other apps didn't. The rider with the BMW C400X recalled a situation where they got lost due to the built-in navigation relying on the phone for GPS functionality, effectively draining the phone battery.

Auxiliary service integration

A positive aspect of using smartphones for navigation was the ability to integrate other services. One rider mentioned their Tesla and that the system of the car automatically integrated with the calendar and other applications on their phone - creating appointments with directions automatically for the rider. Another rider mentioned the positive aspect of being able to make and receive phone calls from a predetermined list of contacts while riding, while contacts outside of that list were sent an automatic text message like "I'm on the road, I'll call you later".

Insights summary - where to go from here

Multimodality in turn-by-turn navigation assistance - a fan favourite
- Several channels gives multiple inputs, increases the chances of drivers turning correctly
- Riders are bothered by turning down the wrong street
- Riders don't want unnecessary information during turn-by-turn
- Choice of modality is personal - no one clear superior modality
- Riders want varying levels of fidelity

Create a multimodal interface artifact
Opens up for the possibility of adding vibration (MOVING kidney belt) - unique for e-motorcycles - Builds upon previous research
Difficult, time consuming to prototype and evaluate
Could be argued to be related to previous research (HUD hjälmar,kidney belt, vibrating handles), Could be argued that these attempts are not practical, not actually usable for "real" drivers, but ours would be. None of them mention electric motorcycles at least.

Drivers stated that navigation doesn't add to the hedonic part of the experience, <u>HOWEVER</u> some stated that navass allows them to focus on the ride (i.e. less cognitive load is used for figuring out navigation) which ties into multimodality and lessening of cognitive load (Van Erp & Van Veen) in a nice way.

Also, one rider mentioned the learning curve of GMaps audio, might be something that can be reduced by multimodality

Interface that enhances the hedonic parts of riding, focus on the "*sensation of riding*" and "*identity*" sections
- Riders are very descriptive and eager to talk about what kind of rides they like
- Riders prefer some roads to others
-
- Riders enjoy the *simplicity* of e-motorcycles
-
- Riders enjoy the attention they get from riding electric motorcycles
- Riders enjoy superiority over cars

How can navigation convey the same *feeling of control* and *simplicity* as the overall e-motorcycling experience? This is pretty much usable in all other projects.
High focus on usability while in-transit opens up possibility for utilizing joystick or something similar

Give moment-to-moment feedback on their stats (grip, G-forces, perfecting the turn)

Concluding information that builds and affirms rider's identity
Uncertain how navigation relates to identity-building/affirming

High resolution trip planning

- Riders are annoyed when the navass brings them on boring roads/highways
- Riders want varying levels of fidelity relating to parts of their ride, some want to plan this beforehand
- Riders sometimes wants to go along specific roads/landmarks - the journey is the goal
- Riders want to see charge points

A compound of Calimoto, GMaps and Chargefinder would satisfy this?

More easily testable, planning is not an activity done in transit

Ambiguous turn-by-turn navigation instructions á la Bee line
-Riders enjoy the *simplicity* and *control*
- Riders enjoy riding "for the sake of it" - a detours and such

How do we avoid creating and evaluating beeline?