InForm

Safer rides with shape changing motorcycle grips

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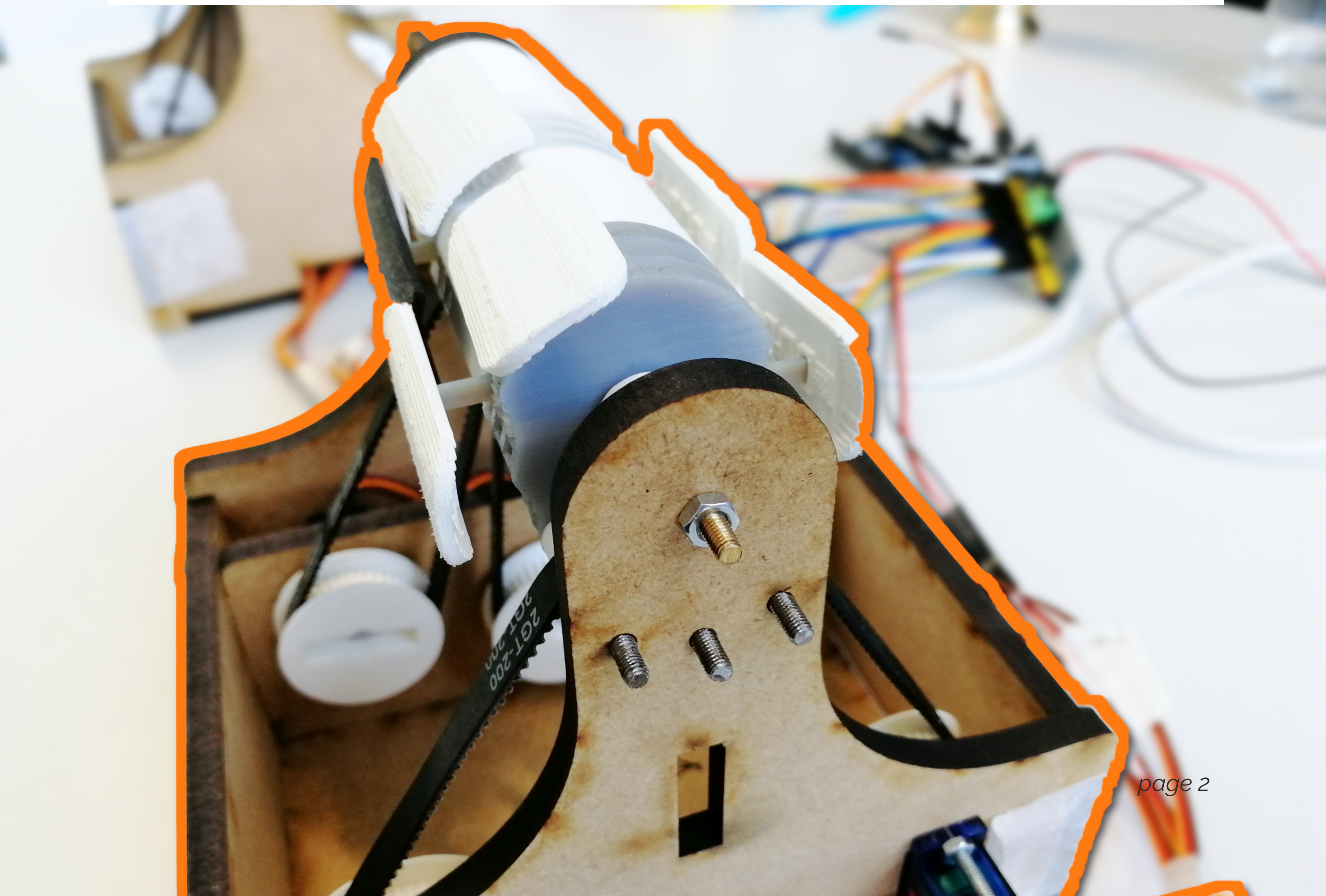
Abstract

It's commonly known that riding a motorcycle is more dangerous than driving a car. Statistics show that motorcyclists are 29 times more likely to die in a crash. One of the most important causes is because motorcyclists are easily overlooked. Products for increasing visibility, such as reflective jackets, do help somewhat, but their effectiveness relies on the attention of other drivers.

Through a process of multiple iterations, InForm was designed as set of motorcycle grips that keeps control with the motorcyclist. They provide environmental information of vehicles in the blind spot and collision warnings through shape change. This helps the rider navigate through traffic safer.

In contrast to contemporary blind spot warning lights or beeps, shape change doesn't require visual attention, but rather adds a layer of information on top of the rider's vision. Results of multiple tests show a positive influence on the rider's environmental awareness and reaction time to hazardous events, thus creating a safer ride.



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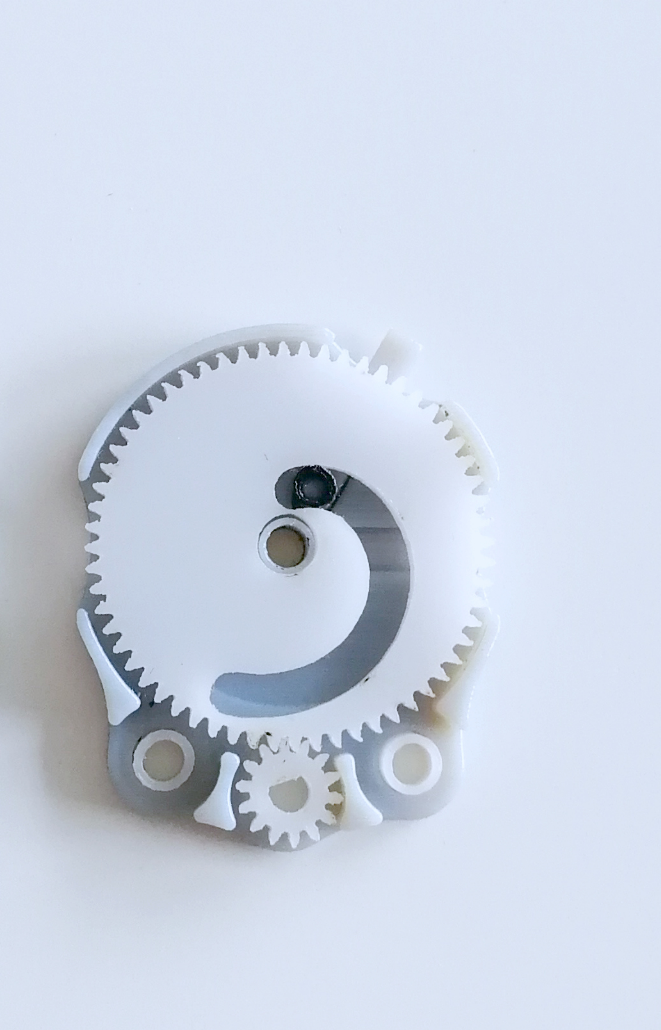


Introduction

Motorcyclists are vulnerable road users, as they are not protected by a car frame or airbags (with exception of expensive air bag vests). Studies show that, per travelled distance, motorcyclists are 20 - 40 times more likely to die in a crash compared to car passengers [26,33]. In the Netherlands, this accounts for 52 and 44 fatal accidents in 2019 and 2020 respectively [12].

Additionally, they are often overlooked in traffic making them more prone to being involved in accidents. Literature shows that the poor visibility (i.e., being seen, not to confuse with vision: the ability to see) can be attributed to three main causes: saccades, selective attention, and contrast.

Many contemporary interfaces rely on visual elements and require visual, focused attention of the user (think of smartphones, despite being illegal to use while driving). Such visual attention cannot be divided over multiple activities simultaneously [4]. Strikingly, driving through traffic requires a high visual workload as 95% of the information is communicated through vision [14]. Increasing attention demanding activities could result in a cognitive failure, where the driver simply misses clearly visible objects including motorcyclists [14,32].

This calls for a design that helps motorcyclists navigate traffic more safely without relying on or introducing new visual elements [14,32]. The aforementioned causes also illustrate why attracting the attention of other road users is unlikely to be very effective, hence the target user are motorcyclists themselves.

A second reason to focus on motorcyclists is because they are an underrepresented target group within the Intelligent Transportation Systems (ITSs) domain, despite the high potential benefits [1,6,33]. ITSs are concerned with safety enhancing technology for a variety of modes of transport, such as ABS and lane assist technology. However, many ITSs are incompatible for motorcycles because they are balance vehicles [1,6]. Nevertheless, motorcycles also open up a new solution domain, being smaller and having better manoeuvrability and acceleration.

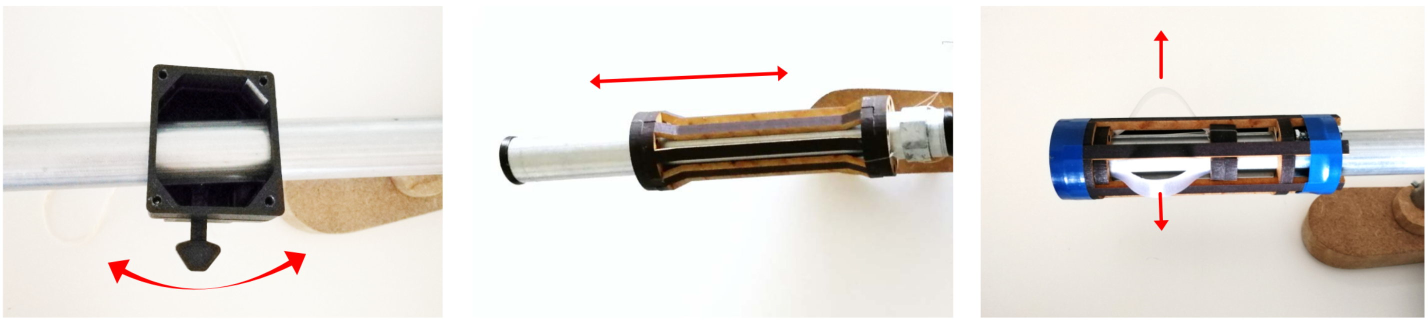
Building on the first M2.1 iteration, this report describes my FMP project on the design of InForm; a set of motorcycle grips that communicate surroundings through haptic shape change. In what follows, some key elements to understand the first iteration are summarized, from there the design process of the second iteration is described followed by the final design of InForm. Finally, the future ambitions for the design and development of InForm are set out.

Summary M2.1 Iteration 1

Literature and user studies illustrated that one of the most important hazards of motorcycling results from (lack of) visibility [21,26], which could partly be attributed to visual information overload [14,32]. An opportunity for improving visibility of motorcyclists opened itself up, however, as mentioned before, by targeting the motorcyclists as a user. This brought about additional design challenges. For example, interaction possibilities and space for an interface are more limited compared to cars and motorcycles are balance vehicles.

The design of InForm focuses on communicating surrounding traffic to the motorcyclist, thereby improving their situational awareness and reaction time, which benefits the safety of powered two-wheelers (PTWs) [33]. The specific information that's being communicated originally is blind spot warnings, collision detect, and intersection support, through twelve expanding panels divided over two grips. By doing so, motorcyclists keep in control over their safety, without relying on the attention of other road users, while also relating to the problem of poor visibility.

The most promising type of feedback is haptic shape change. This decision has to do primarily with the visual information load of traffic. Haptics was therefore a promising alternative, already explored for similar purposes in cars [14,16,19]. Multiple variations on tactile/haptic feedback were explored and tested in the first iteration, including force feedback in the indicator switch, moving grips and shape changing grips (fig 1).



Force feedback | Motion feedback | Shape changing feedback

fig 1: Three explored feedback types of iteration 1.

The haptic steering wheel designs [14,16,19] show a promising alternative to solve the issue of visual information overload, but they are all designed for cars. The feedback is mapped to a circular steering wheel and needs to be translated to a straight handlebar/grips. The mapping between the feedback and intended action of the steering wheel is also much stronger than for motorcycle handlebars, since turning a motorcycle happens mainly through body position, not by turning the handlebars. Secondly, vibrations in the handlebars would likely go unnoticed due to the vibration "noise" of wind and the engine. Vibrations inside gloves or gear could be cumbersome to install and might be forgotten. Other considered feedback types, such as heat or sound, were not responsive or precise enough to present added benefit in this context. What's more, the application of tactile, rather than audio/visual feedback, does seem to improve the reaction time, which is an essential aspect of collision avoidance. In addition, up to five different states were possible to differentiate according to [16], although the study did not elaborately report the results. Therefore, shape change was pursued as it seemed to have the most appropriate characteristics.

Positioning the feedback in the grips ensures a consistent and continuous perception of the feedback, which is one of the main limitations of similar products. Blind spot detection is often implemented as feedback lights in mirrors that needs to be seen by the driver [9,20,23,31,34,36]. The way of providing situational feedback relies on abstract visual cues. Feedback could be missed, especially in bright sunlight, and it lacks information about the seriousness of the hazard. Even worse, it requires a trade-off between attention on the road or feedback lights, it cannot be parallel, thus disrupting the motorcycling activity. Haptic information can, provided being naturally mapped to the environmental information, be perceived in parallel with vision [18,32], making it an additional layer of information, instead of a replacement.

The first iteration was concluded with a shape changing grip design (fig 2) that showed promising results for improving situational awareness, but still required testing in a (simulated) context to evaluate how well the patterns matched the environment, what reaction they evoke, and which information is most relevant to communicate, as well as establishing a more concrete measure of the improvement on safety.

fig 2: Final prototype of the first iteration.

Related work

This section discusses some areas of related work regarding traffic safety and some alternative feedback modalities. The work discussed here elaborates on the related work of iteration 1 (i.e., the M2.1 report). Firstly, the most important causes for poor visibility of motorcyclists are described in more detail. Next, common feedback modalities and their limitations in transportation are discussed. Finally, related work on perceiving tactile feedback is provided.

Poor visibility of motorcyclists

Literature shows that the poor visibility of motorcyclists can be attributed to three main causes. These causes are an important element when designing to improve motorcycle visibility, hence they are explained in more detail here.

Saccades

Most of the image people see is filled in by our brain and only a small point is actually in focus. While scanning around, the brain creates a complete picture of all the small bits of information it received from rapid eye movements, called saccades. Since motorcycles make up a relatively small part of our vision, they tend to be missed by our eyes, especially if they are going fast. [5,17]

Selective attention

Selective attention causes inattentional blindness (fig 3), which occurs when people fail to consciously perceive a task-irrelevant object [11]. Car drivers, who search for hazards before crossing intersections are prone to ignoring a motorcycle, simply because it is not perceived as a danger to them [15]. In other words, the motorcycle is task-irrelevant while scanning an intersection and is suppressed from processing in the brain [13].

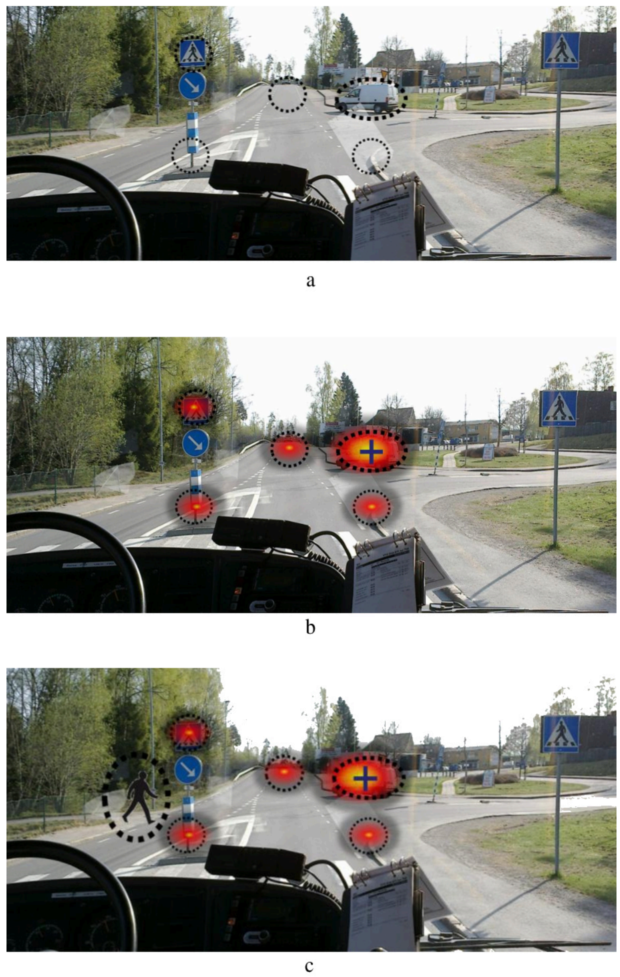


Fig 3. "Conceptualization of inattention in terms of mismatches between the driver's actual resource allocation (heat maps) and that demanded by activities critical for safe driving (dashed rings). The attentional activation level is represented by the intensity of the heat map while the activation demanded is represented by the line width of the rings. The "+" represents the current gaze direction" [15].

Fig 4. Top: common blind spot warning light integrated in a car mirror. Bottom: rare motorcycle add-on for a blind spot warning light.

Contrast

People perceive motion and high contrast better and since motorcycles are relatively small and usually black, together with the commonality for motorcyclist to wear black gear, they will be much harder to see than larger and brighter coloured vehicles. Especially in low light situations, or when the sun blinds the person approaching you. [17]

Feedback in transportation

In the automotive industry, an increasing amount of feedback is being developed for applications that vary from entertainment systems to warning signals. The most common feedback modalities are sound and visual icons or lights [14,32] (fig 4). Traditional warning sounds are mostly composed of single or multiple beeps and are used to convey information of various warning signals including forward collision, lateral collision, and lane departure warnings, etc. [32].

Since driving is a task that requires visual input, researchers recommend limiting the display of additional visual information [14,32]. Recently, the sense of touch has become a more common information source because there is no need to look at the source while interacting. Tactile feedback can be used to increase task performance, reduce mental and visual load, and improve on the perception of warning signals, amongst others [18,22,32]. Examples of tactile or haptic feedback are increasing in popularity in car steering wheels (e.g., [14,16,19,24]) (fig 5), but examples for applications on motorcycles are rare [1,6,33].

Fig 5. Prototype of a steering wheel with haptic (vibration) feedback.

Perception of tactile feedback

For the brain to correctly interpret information, it is not necessary that it be presented in the same form as the information it is building onto [2]. The visual information of the eyes can be interpreted similar to haptic information that is representing the same information, as "*we see with the brain, not the eyes"* (p. 285) [3]. This even stretches to an extent where one of the senses is completely lost and needs to be replaced by another sense [2]. Studies have shown that, once learned, it is possible to understand information as detailed as low-resolution camera footage purely from haptics (1032 points), where the pressure and location of the haptic points is mapped to the camera's vision. This information also includes a direction and location in 3D space. It takes about an hour to learn to pick up a moving object purely from the haptic stimuli, i.e., without seeing the object [2].

A benefit of using tactile feedback in these contexts is that information transmission of the skin is much faster than the eye [2]. This is also beneficial for the application of tactile feedback in traffic, where information is required to be perceived and interpreted in fractions of a second. Collision detection (which is part of environmental awareness) could improve reaction time, where a 0.5 second improvement can prevent about 60% of the rear-end collisions, and 1 second can prevent about 90% [1,14].

Design process

The design process of the second iteration is built around a higher quality implementation of the haptic shape change feedback inside (motorcycle) grips. The implementation is used to test and fine-tune haptic stimuli for the purpose of improving situational awareness, determining which information about the surroundings is useful, and evaluate how it should be communicated and balanced with varying levels of danger. A key requirement for the prototyping and design process is the inclusion of a more realistic context.

Stakeholders and partners

To gain support from stakeholders in related areas, numerous companies were contacted at various points in the process, including BMW Motorrad, Yamaha, Bosch Mobility Solutions, van Moof (for speed pedelecs) and TNO. Unfortunately, none of those companies agreed to a collaboration.

Risks and assumptions

What follows is a design process of three (sub)iterations, each with specific goals and questions. Ultimately, these iterations address the highest-priority risks, questions and assumptions for the success of this concept as extracted from Iteration 1, including:

- *The perception and interpretation of various states / levels of detail,*
- *The effect of context on perception and interpretation,*
- *The effect on reaction time*
- *The look and feel in terms of functional and aesthetical properties*
- *The technical implementation in terms of mechanics, software, materials, and sensor selection.*

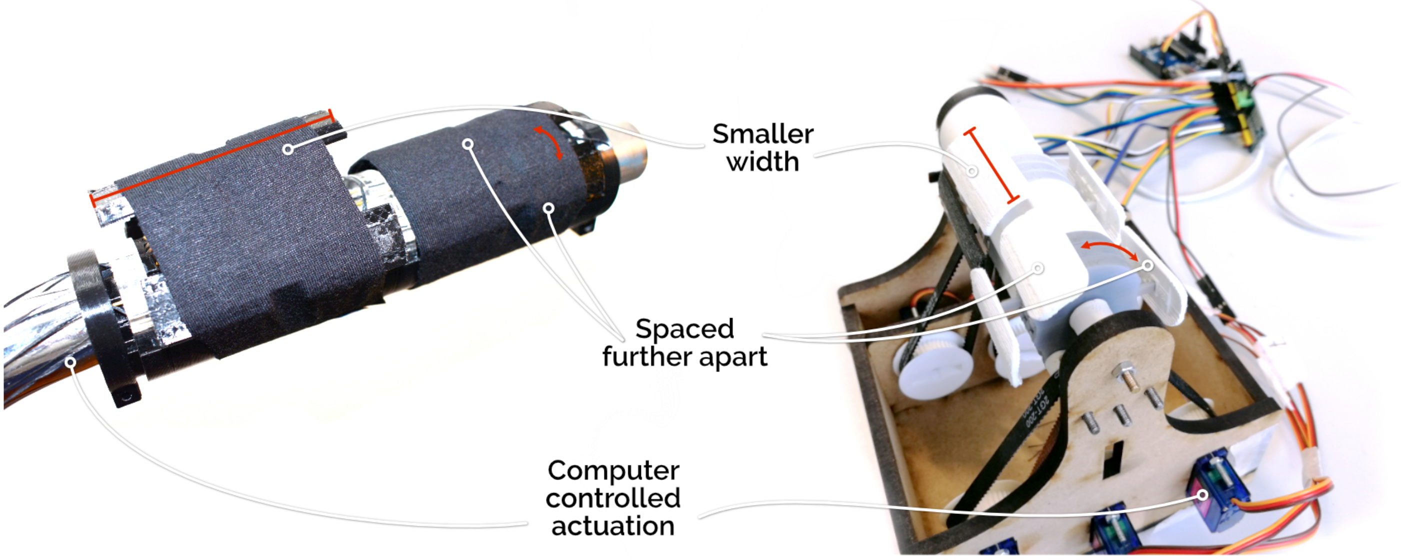
Iteration 2.1 - Perception and interpretation

The goal of the first iteration is to conduct an experiment that evaluates the perception and meaning of tactile feedback states in relation to the environment. In other words, the mapping between the system's feedback and the environment. A preliminary experiment in the first iteration of InForm indicated a few points for improvement which are tackled first. These are implemented in a refined, tougher, and more versatile prototype to conduct the experiment with.

The preliminary improvements include (see fig 6):

- *Relocating the front panels slightly more down, to push on the fingertips and thereby emphasizing the difference between center and forward directing feedback.*
- *Making the width of the panels smaller, so they both fit within the palm of the hand.*
- *Improving strength and timing of the actuation by using computer-controlled actuation.*

Fig 6: Former prototype on the left, revised prototype on the right.



Mapping environment to feedback

In the first iteration, much effort was put into background research and benchmarking. This research included blind spot warning systems mainly from the feedback point of view. Sensing was identified to be done using either radar or camera technology, but what environmental state would trigger certain feedback states was not considered yet. The environmental state refers to the situation around the user, such as lane changing or approaching vehicles.

Relevant details here are for example the distance of giving feedback. Too far and the information will not be meaningful and trigger too often, too close and there is no time to respond to the feedback. Secondly, what happens in a situation that combines multiple warning states, such as collision and blind spot warnings. Existing blind spot warning systems mention a sensing distance of about 30ft or 10 meters with a width slightly less than the adjacent lane, i.e., about 2.20 meters on each side [20,23,29,34] (fig 7). However, since a motorcycle is smaller than a car, this range might need to be extended to about 3 meters. Vehicles inside this range will trigger a (mostly) visual warning light. Some include a direction indication [20] (fig 8).

Automated emergency manoeuvres are not suitable for motorcycles due to their balance. Therefore, reaction time in traffic should be accounted for, for which the rule of thumb in the context of traffic suggests one second [35], even though the reaction time should be decreased by using InForm. The distance covered during reaction and stopping relies on the speed and braking power of the motorcycle. Higher speeds require more timely warnings. On a dry road, the stopping distance can be estimated using the formula:

$$d_{stop} = d_{reaction} + d_{braking} = \boxed{v_{km/h} / 3.6 + (v_{km/h} / 10)^2 / 2}$$ [35].

This would be a reasonable initial distance to trigger forward and lateral collision warnings. All-round collision detection (i.e., not limited to frontal and rear) is a complicated process that entails many variables and complex algorithms, especially for motorcycling [7]. Nevertheless, these identification processes are beyond the scope of this design project. Figure 9 shows the mapping between environment and feedback for InForm in more detail

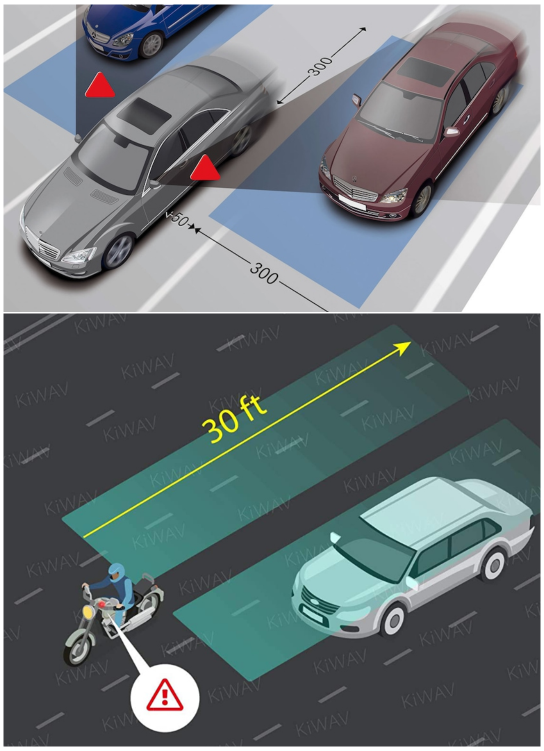


Fig 7: Some example sensor trigger distances. Top: 300 x 300 cm, bottom: 30ft.

Fig 8: Innov thirdEYE optical direction feedback. Triangles indicate left or right hazards, squares straight behind.

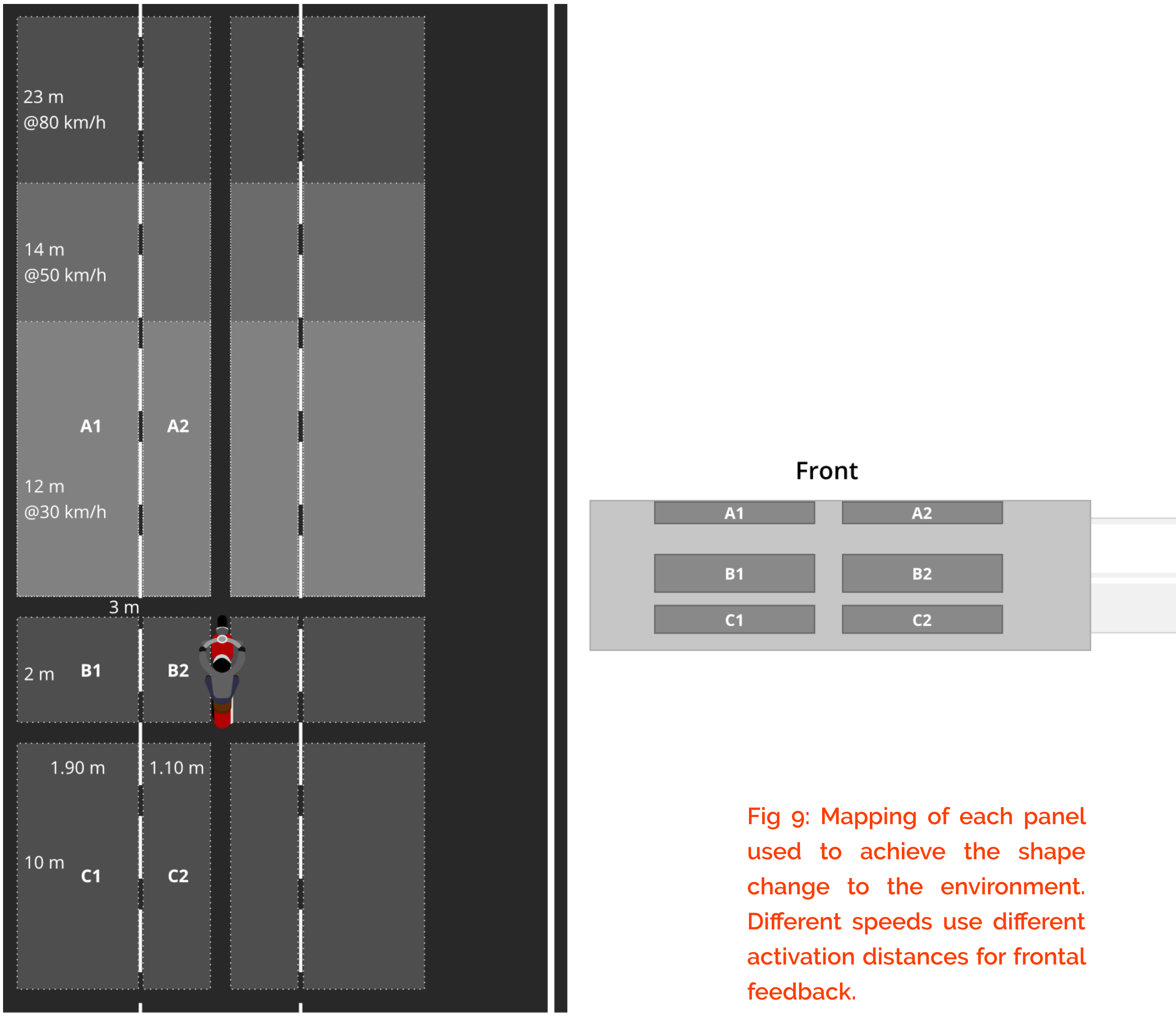


Fig 9: Mapping of each panel used to achieve the shape change to the environment. Different speeds use different activation distances for frontal feedback.

Expert evaluation

In an expert evaluation with an automated driving and human interaction designer, the concept and implementation of InForm were discussed. From this discussion, a set of risks were identified that require testing to validate the effectiveness and value of the design, which are summarized in fig 10. The risks are included as sub-questions in the objectives of following experiments.

According to the expert, predicting the behaviour of surrounding traffic would be a valuable component of a product designed to provide timely warning signals. This would benefit the effect on reaction time and place the design at the forefront of current innovations within the automotive domain.

Attracting covert attention

For providing the feedback, an important distinction was made regarding overt attention (what we see) and covert attention (peripheral attention, where we don't look). While riding a motorcycle, the motorcyclist is focusing on traffic, signs, road surface hazards, etc. This is part of overt attention. Haptic feedback of InForm would take place in the covert attention, to prevent a visual information overload and the necessity to switch attention from feedback to activity (driving in traffic). Care needs to be taken not to attract overt attention to the grips while providing feedback (i.e., triggering the user to look at their hands when receiving haptic feedback), as the feedback is meant to guide the attention of the rider towards a hazard, not the location of the feedback.

AI predicting traffic behaviour

Opportunity out of the project's scope

Will informing feedback cause a cry-wolf effect?

Requires long term testing

How intense should the feedback be to preserve control, yet communicate the environment clearly (speed, distance, etc.)?

Where to will the shape changing feedback attract attention to? (Overt vs. covert attention)

When to provide feedback based on reaction time and considering information overload?

Will the shape change impede handling of the motorcycle?

Is the feedback naturally mapped to the environment?

How to balance the importance of the warning to the haptic experience?

Fig 10: Key take-aways of expert evaluation.

Feedback mapping for parallel perception

In addition, the feedback needs to be naturally mapped to the traffic situation, i.e., require little learning to understand the information, and this requires testing the haptic experience in a context. According to the multiple recourse theory [37], it is possible to perceive both visual and haptic information, as long as they are naturally mapped. For example, you can play piano and read music, but not read a book, at the same time. Whether the current feedback implementation naturally maps to the surrounding traffic requires testing as well.

Limiting feedback occurrence to prevent a cry-wolf effect

Furthermore, the timing of the feedback was discussed within the light of the cry-wolf effect [8], which happens when continuous false alarms result in failures to respond to actual alarms as well, diminishing the usefulness of the grips. This means a fine balance needs to be established between timely and relevant feedback. Here the addition of predicting traffic behaviour would be fruitful as false alarms can be limited, yet feedback can be provided in time to actually perceive, process and act on the hazard.

At this moment, InForm implements two magnitudes of information: continuous awareness through the outer set of panels, and acute warnings through the inner set of panels. The latter embody nearby hazards, where the former is there to inform and prepare the rider for potential acute reactions. When expecting a cue, humans are able to react within about 200ms, which argues for the value of the outer set of panels. Long-term studies should validate whether the cry-wolf effect will surface from the continuous feedback of the outer panels. Additional tests need to validate the riders' understanding of the difference between informing (outside) and warning (inside) shape change. Such a validation provides sooner insight into the risk of the cry-wolf effect and thereby informs modifications in trigger distance of the panels. Perhaps even omitting either the warning or informing panels altogether.

Balancing danger level with attracted attention

Another problem pointed out by the expert is the risk of attracting attention to less important situations. A sort of decision-making process could be included to prevent attracting attention to the wrong -or less critical hazards. However, acute warning signals (the inner panels) embody obstacles nearby the motorcyclist, and their change in size communicates the severity of the warning. This information is meant to work in parallel to other senses of the motorcyclist, hence not distracting from other hazards. This hypothesis should be tested in terms of how natural the haptic feedback matches with other senses for it to be understandable in parallel. Modifications in terms of shape change speed and reach can be made to better fit the relative importance of a warning.

Ergonomics

Finally, there is the discussion about ergonomics. Increasing the size of a grip might make it more difficult or less comfortable to hold, thereby impeding the handling of the motorcycle which would cause danger. Also, people with different hand sizes will have a varying grip on the panels. Whether it is possible to design a uniform size and shape is difficult to predict. Alternatively, different sizes could be made, just as is done with gloves and other types of clothing.

Prototyping

Initially, BYJ48 (5v) stepper motors, controlled by an Arduino MEGA ADK and ULN2003 driver were used as actuators, but these were neither strong nor fast enough. Therefore, twelve SG92R high torque servo motors were used, in combination with an Arduino Uno and an I2C servo driver. The servos are powered by a 20-Watt 5v adapter to provide sufficient current for each motor. They rotate a metal shaft through a pulley-belt transmission which ultimately connects to a high ratio set of gears to increase torque and maximize the reach of the shape change to about 10mm per panel (fig 11).

The inside consists out of a base with a cam gear that is driven by the smaller drive gear, which is connected to the shaft, and thus servo motor (fig 12). The cam gear is what translates the rotational motion into a linear motion by pushing a follower up and down. The follower is connected to an arm and a panel, which is what finally pushes against the hands of the user (fig 13).

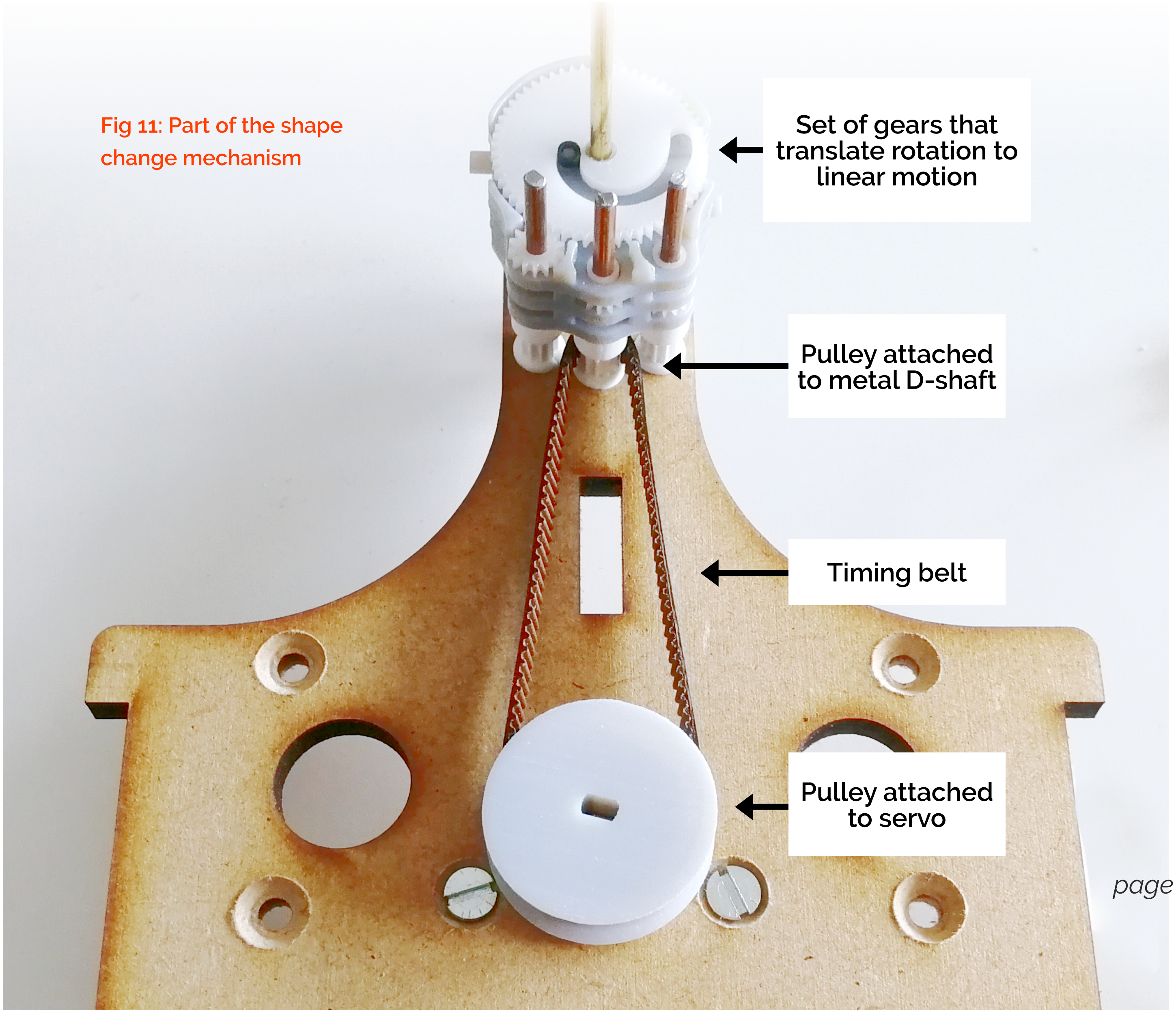


Fig 11: Part of the shape change mechanism

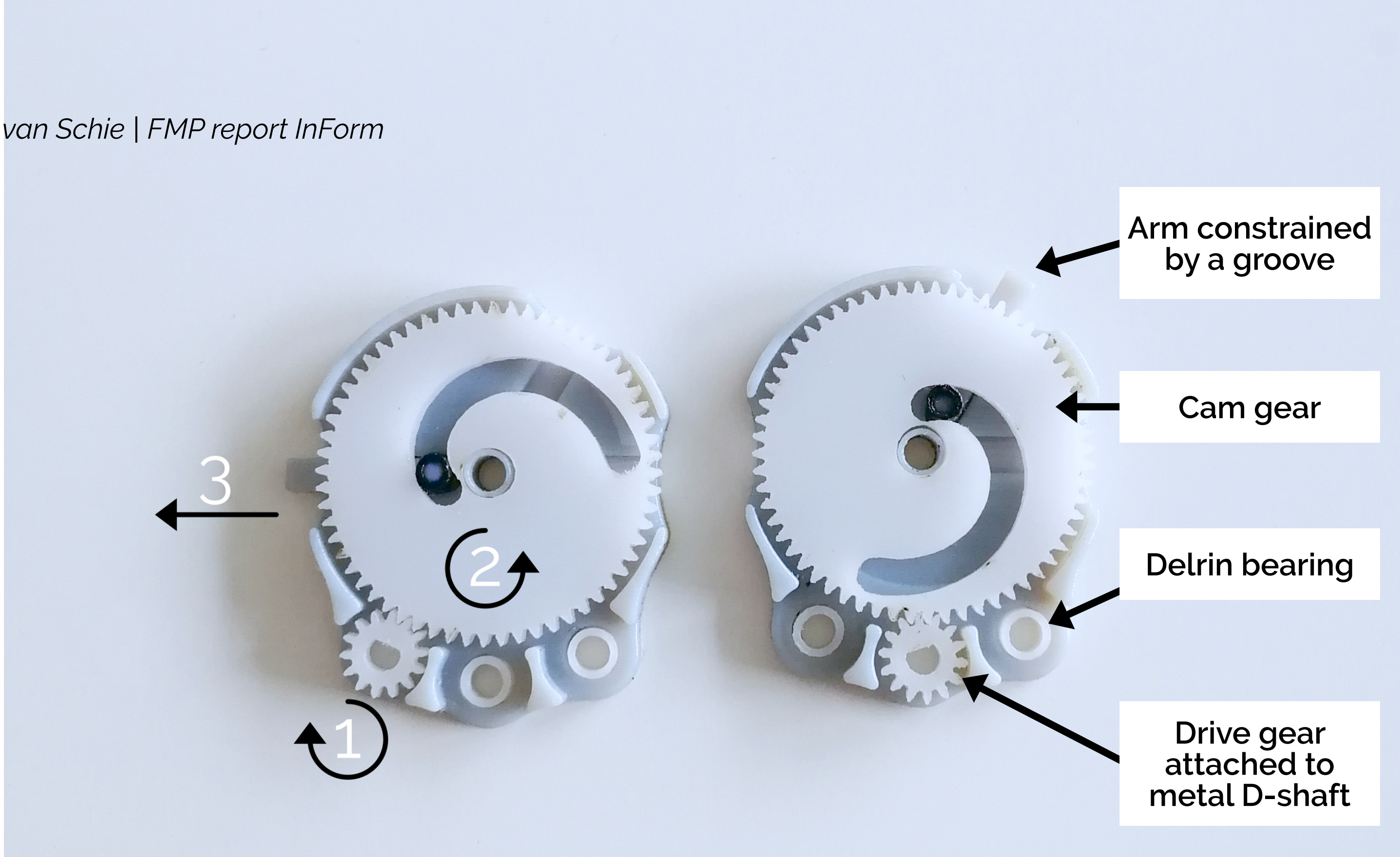


Fig 12: Part of the shape change mechanism. Translation from rotation to linear motion

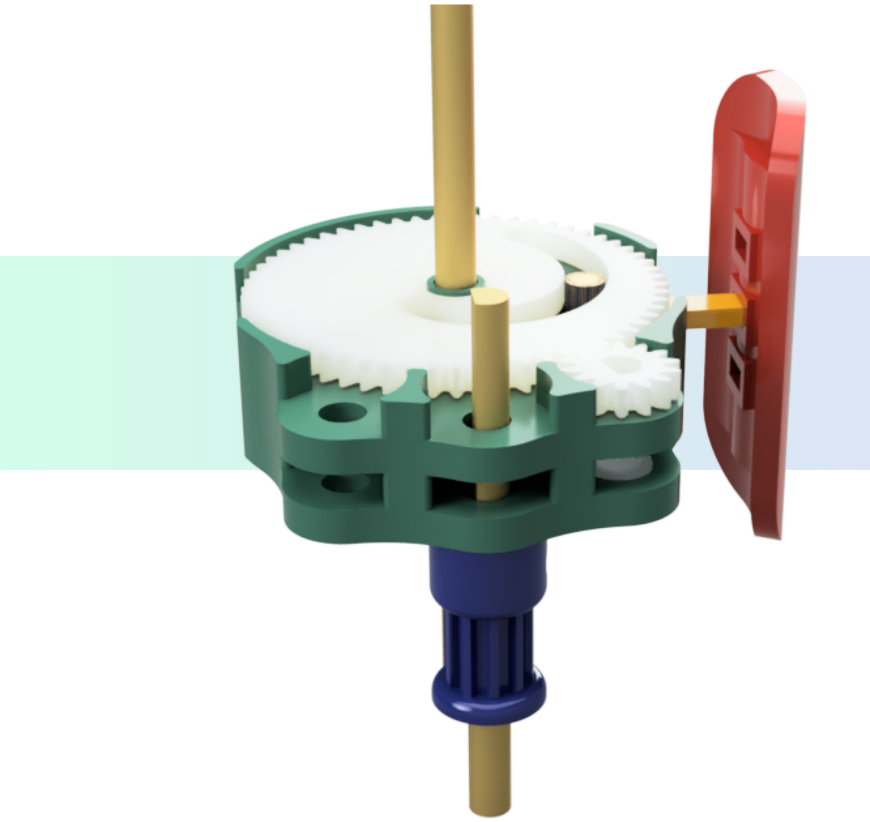


Fig 13: Two layers of the 3D CAD model showing the shape change mechanism.

The biggest challenge for this prototype is realizing enough strength to overcome the force of someone's (light) grip while keeping everything about the size of a regular grip (about 32mm in diameter). Secondly, due to the unpredictability of traffic, it was necessary to be able to control each individual panel separately. This was achieved by using three shafts to drive a stack of spiral gears, where only one drive gear is attached to an individual spiral gear (see figure 14). Everything is packed together into a 6mm MDF casing, which also functions as guides to support the shafts. This prototype was made for the purpose of testing variations on the shape change patterns, and was intended to be used for multiple iterations and experiments. Therefore, much time was spend optimizing the mechanism to include control over the location and expansion of each individual panel.

In the process many variations on the mechanism were made in order to overcome these challenges. Multiple iterations were done with materials and manufacturing methods, as 3D printed PLA might work well for quickly validating a motion, it is not particularly sturdy, nor is it precise enough for this scale. The gears are made from Delrin (a.k.a. POM) using a high-precision laser cutter. Delrin is a nylon material commonly used for making gears. These gears are fitted onto a 3mm metal D-shaft, which was custom made with a milling machine (fig 15). The panels require less precise margins, so 3D printed PLA was sufficient here. The base and arms required higher precision; therefore, these were printed with an Objet Connex 350 3D printer. The high resolution also makes the components a bit stronger than the rather "rough" layers of a less expensive FDM printer.

Fig 14: Each servo actuated another arm, and thus panel.

Fig 15: Milling the D-shafts

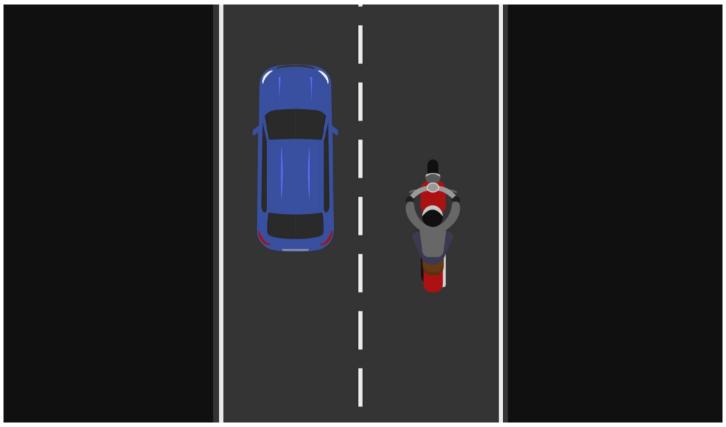


Fig 16: Example of top-down animation used to sketch a context

To control the shape change, a Processing sketch is run showing top-down animations (fig 16) that convey the context. These animations are linked to a CSV file containing the expansion for each of the twelve panels with intervals of approximately 20ms, that is read by Processing and send to the Arduino via the serial bus. The timing of the expansion values (between 0 - 1) is matched with the play time of each animation (fig 17). An additional option was included that only required a CSV file with expansion values and a time stamp. This made experimentation with new or adapted patterns easier. Appendix A includes the code, animations, and CSV files used in the experiment that is described next.

Preparation of shape change

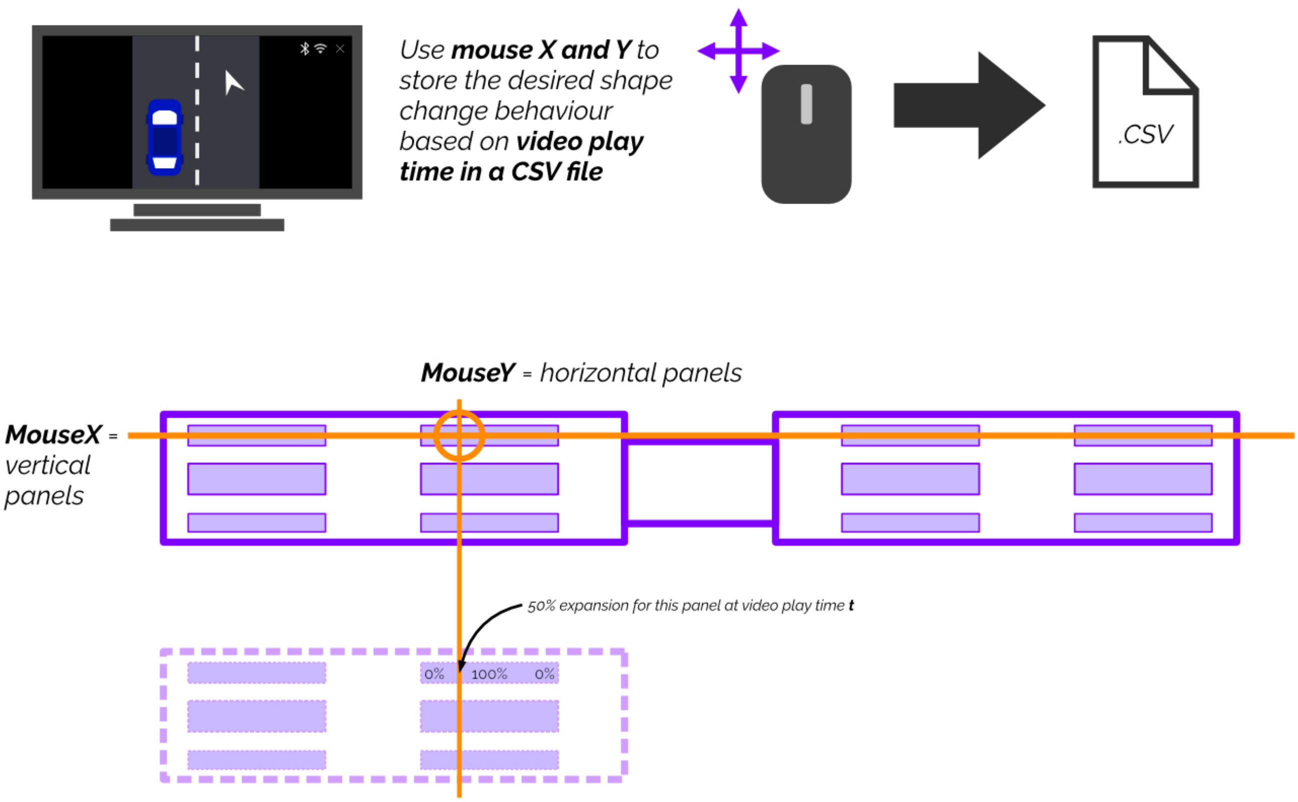
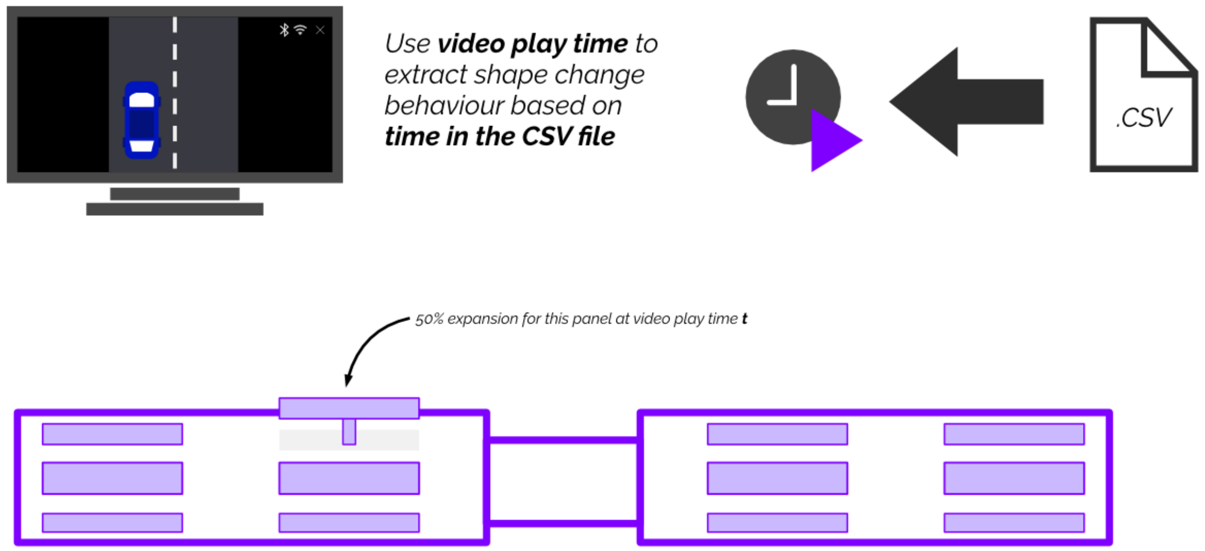


Fig 17: Schematic overview of the Processing code

Reproducing shape change



Method

Objective

The goal of this experiment is evaluating the perception and interpretation of tactile feedback states in relation to a representation of an environment that could distract from perceiving or influence the meaning of the feedback. The feedback states are the transitions from state to state that are being used to communicate various attention demanding situations in traffic (fig 18 - 20). Relevant to the main objective are the following sub-questions:

1. Is the feedback naturally mapped to the environment? This would make it possible to process visual and tactile information in parallel.
2. Will the tactile feedback attract attention to the dangerous situation (covert attention) or the hands (overt attention)?
3. Are participants able to distinguish informing from warning feedback?
4. Does the feedback help support situational awareness?

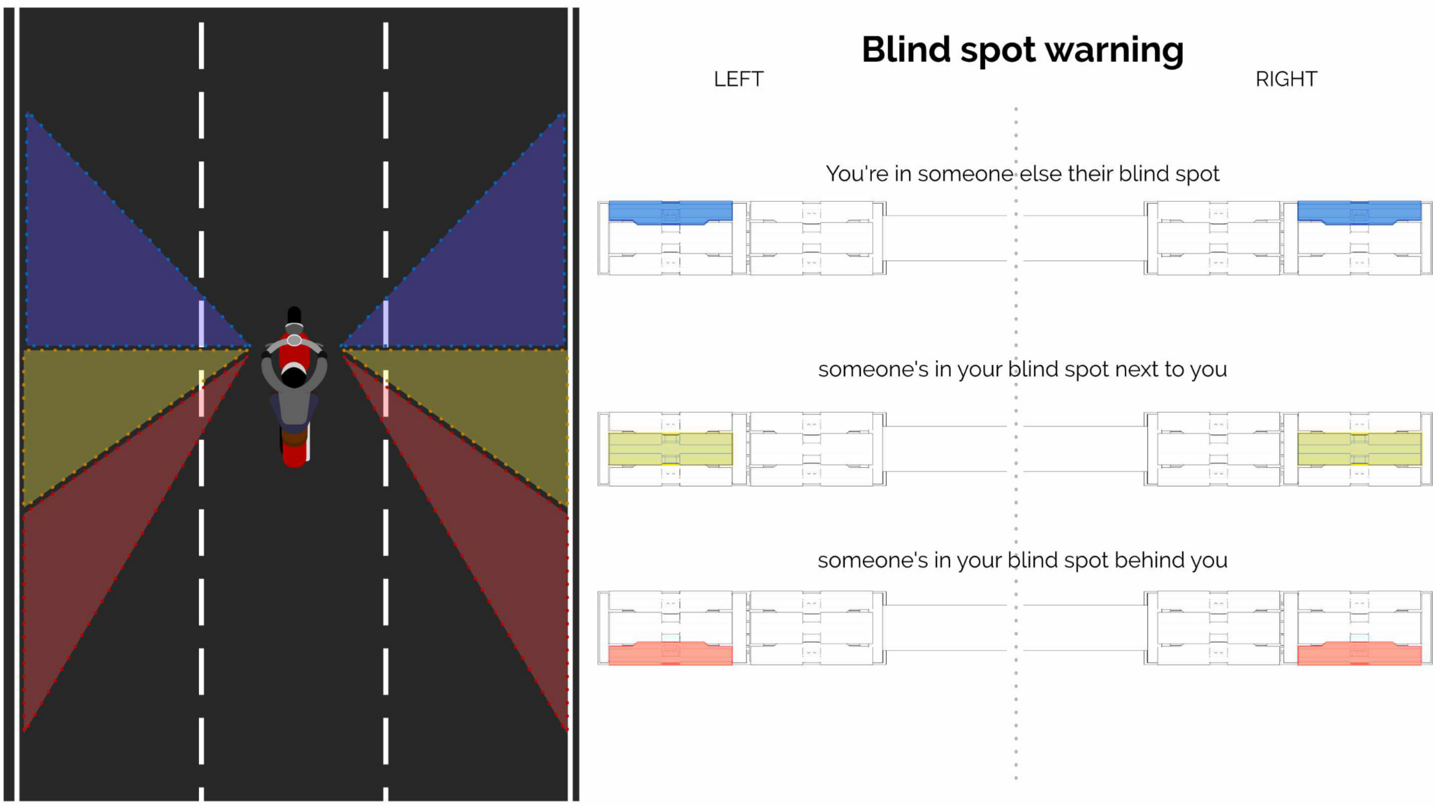


Fig 18: Feedback states based on vehicles in the blind spot

Collision detection

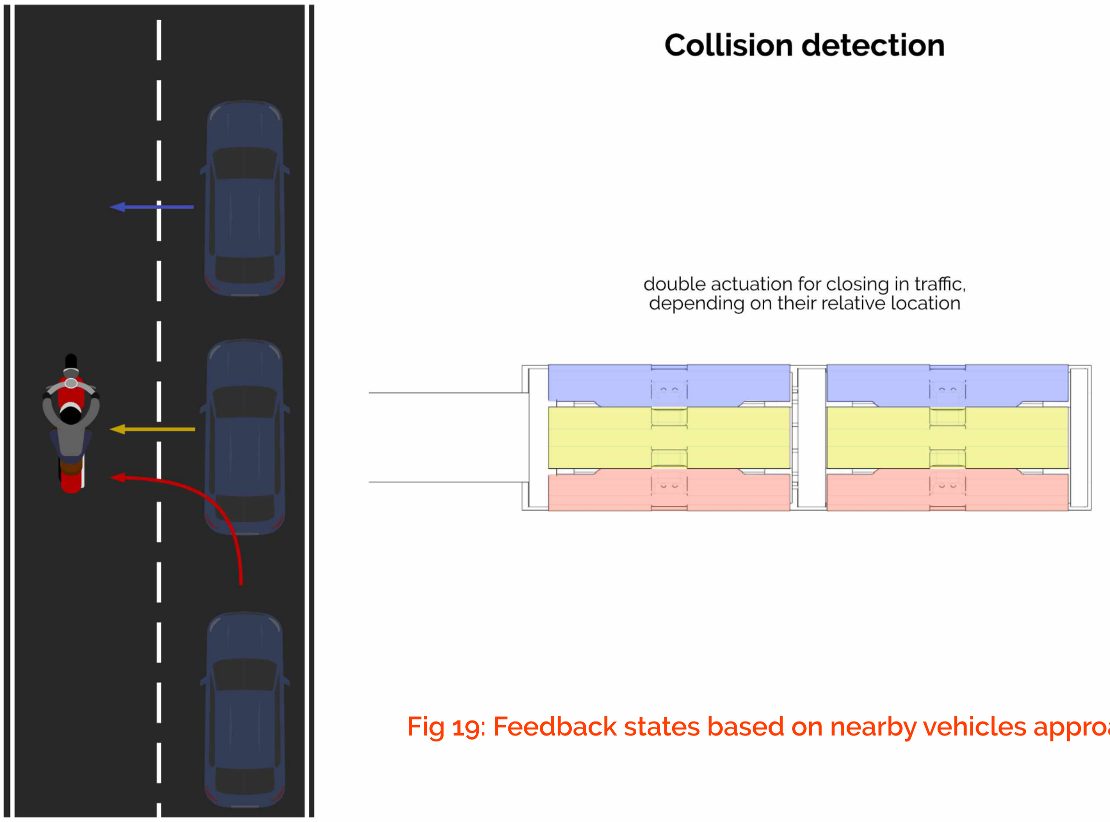


Fig 19: Feedback states based on nearby vehicles approaching

Intersection support

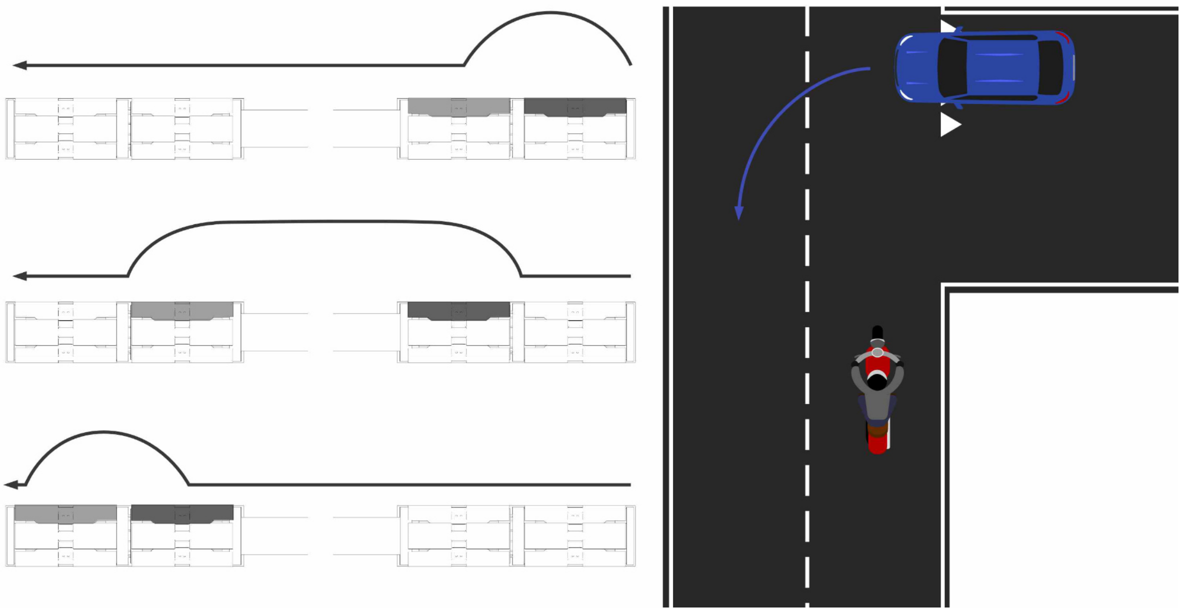


Fig 20: Feedback states based on crossing vehicles

Participants

For the experiment, eight participants (n=8) were recruited via a personal network. Participant were selected based on having a motorcycle license, as the experiment tests perception and understanding of hazardous traffic situations from the perspective of motorcyclists. The sample includes varying genders, ages, years of motorcycling experience, and self-assessed experience level. Before conducting the experiment, the study was ethically approved with an ERB form, and participants' explicit consent was given to participate and collect their data using a consent form.

Materials

Central for this experiment is the shape changing prototype describe earlier. The prototype is a set of handlebar grips that provide the tactile experience. The context is illustrated using a set of short top-down animations, displayed on a laptop, mapped to the shape changing feedback. This allows for a controlled experiment in which all feedback states can be tested. In total there are 9 unique scenarios used for the experiment (see table 1). Lastly, the data recording materials include a video camera and microphone of a phone, observation and interview notes, and participants' sketches from the interpreted scenario.

Table 1 - Scenario description experiment 1

Scenario	Description
1.	Vehicle in your blind spot slowly passes you
2.	Vehicle in your blind spot changes lane right behind you
3.	A vehicle drives up really close behind you at a traffic light
4.	Vehicle next to you cuts you off
5.	Vehicle just in front of you cuts you off
6.	You enter a vehicle's side-way blind spot
7.	You enter a vehicle's rear blind spot
8.	A car pulls out in front of you from a side street
9.	A car driving the opposite direction turns left in front of you, crossing your lane

Procedure

To test the perception and meaning of the feedback states, participants (n=8) are first acquainted with a randomized sub-section of the feedback states. These are not linked to any context yet but are only in place to set an expectation baseline for the participant. A brief prior experiment (in iteration 1) namely indicated a short learning curve, that might be mitigated with this procedure. During the experiment, the position of the participants' hands is corrected if they do not touch the panels sufficiently.

After the introductory phase, the participants will experience two rounds of scenarios, taking about 15 seconds per scenario. A (1) blind round and (2) visual round. The scenarios are randomized to account for influence on meaning based on similar tactile experiences during the test.

The participants will first experience the scenarios blind, i.e., without the visual information of the videos, as this isolates the haptic perception [22]. After each scenario, participants are asked to describe their perception of the feedback. Relevant questions that are asked to elicit that information include: what and where they felt the feedback in their hand, where they think it points to, what motion they experienced, and how serious the feedback felt. Secondly, they are asked to draw out the scenario they think they felt in order to document the interpretation of the tactile experience. For this, an example was provided (fig 21).

Finally, after going through all scenarios, the experiment is concluded with a short discussion in which the least/most clear scenarios are discussed, as well as the perceived usefulness of the feedback.

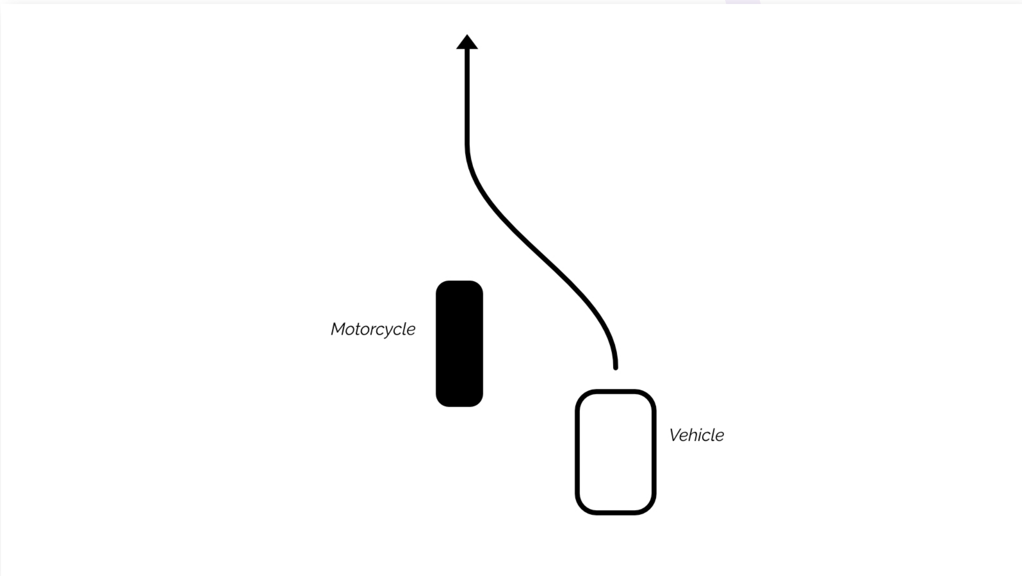


Fig 21: Example sketch for participants to draw out interpretation

Data collection

Data is recorded during the whole experiment by recording sound and filming the participant's hands using a camera suspended above the prototype. During the experiment, observation and interview notes are made and the interpretation drawings are documented on a blank sheet of paper. See fig 22 for the study setup.

Analysis

The results are used to find how well the perception and interpretation of the feedback match with the designer's intention. In other words, the participant's mental model is compared to the designer model [27,28]. The usefulness is analysed using inductive thematic analysis [10]. The experiment sub-questions are a guide to help identify what data is relevant for the themes without being limited to a set of pre-defined categories. Improvement points are elicited for achieving a useful amount and type of feedback that allows for quickly and correctly interpreting and reacting to the situation.

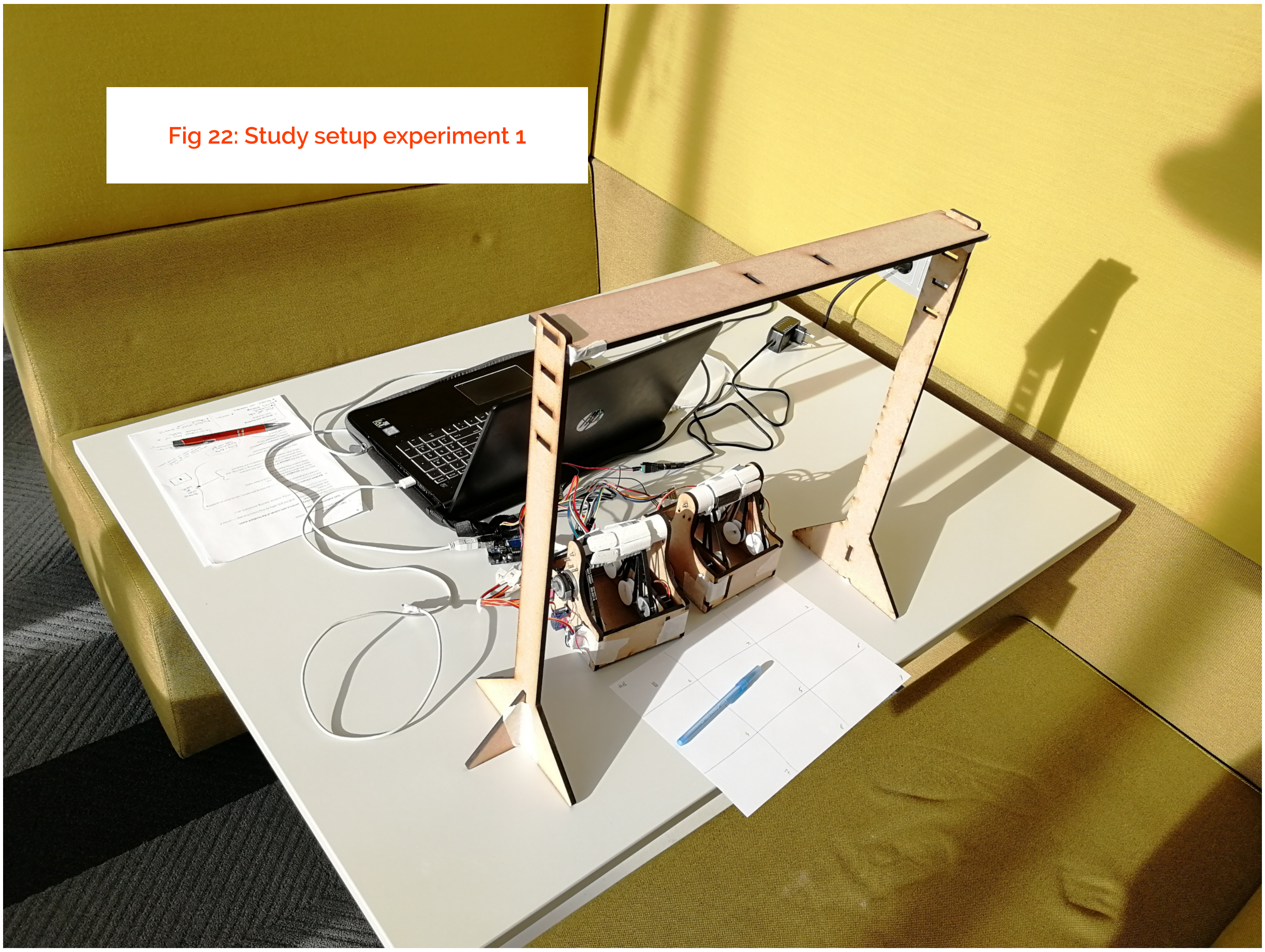


Fig 22: Study setup experiment 1

Results

The experiment results were analysed on three different axes: the perception, interpretation, and usefulness. The first two are observed and compared to the designed scenarios using scores based on fully, partially -and incorrect perception and interpretation of the feedback. Table 2 shows a quantitative comparison between mental model and designer model. Additional comments during and after the experiment are analysed using inductive thematic analysis to find the most useful features and use cases now that the concept is more refined (as compared to the exploratory phase a few months ago).

Perception (see fig 23)

Perception of the feedback was often difficult to recall but was always felt correctly when describing the perception at the same moment of perceiving it. Participants were inclined to ask for feeling the feedback twice. When blindly perceiving the scenarios, participants were often looking up or away from the grips, and when the visual information was provided, they looked at the display. Only occasionally participants looked at their hands. Noteworthy is that the outside rear panels did not touch the palm of most participants, due to their hold on -and the rotation of the grips.

For scoring the perception in table 2, only the participants that correctly mentioned the complete shape change of the panels were scored "correct". Participants that described part of the shape change were considered "partly correct" and were not used to calculate the total perception scores. This results in rather low scores, but we must consider that the shape change patterns were quite elaborate and took about 15 seconds to complete. Participants scoring "partly correct" understood the general direction and motion of the feedback, but did not describe details, such as which individual panel they felt. Considering this

Table 2 - Participants' mental model compared to the designer model

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Total perception correct % *(n= 72)*	Partly correct % *(n = 72)*
Perception *(correct / partly correct / incorrect)*	6/1/1	5/3/0	8/0/0	3/5/0	4/4/0	5/2/1	3/2/3	3/4/1	5/3/0	54.0%	87.5%
Interpretation *(correct / partly correct / incorrect)*	4/2/2	0/5/3	5/0/3	1/4/3	3/1/4	2/2/4	3/2/3	2/3/3	4/2/1	33.0%	62.5%
Total perception correct % *(n = 8)*	75.0%	25.0%	100.0%	37.5%	50.0%	50.0%	37.5%	37.5%	62.5%		
General direction and motion correct % *(n = 8)*	87.5%	62.5%	100.0%	100.0%	100.0%	87.5%	100.0%	87.5%	100.0%		
Total interpretation correct % *(n = 8)*	50.0%	0.0%	50.0%	12.5%	37.5%	25.0%	37.5%	25.0%	50.0%		
Total general situation correct % *(n = 8)*	75.0%	62.5%	50.0%	75.0%	50.0%	50.0%	75.0%	62.5%	75.0%		

level of perception, the scores are considerably higher and indicate that the shape change patterns are consistently perceived in terms of general direction and motion.

Left and right were never confused, as were motions from one side to the other. However, from in total 40 occurrences including rotation (5 scenarios x 8 participants), 6 were perceived the wrong way around without visual information (i.e., the scenario animations). When rotation was combined with sideway motion in one hand (L-shaped motion), the inside panels were not perceived by half of the participants.

Actuation of both inside panels at the rear or front were 6/16 times not perceived as behind or in front, respectively, when preceded by motion from one side to another. The motion was perceived to continue, i.e., the feedback seemed to point to left or right, depending on the direction of the preceding motion. Without the sideway motion, the dual actuation of inside front or rear panels was perceived correctly by all participants.

On a similar note, quick motions, or large expansions (i.e., high contrast) were easy to perceive. However, when combined with relatively subtle feedback (i.e., slow motion and/or limited expansion), participants 10/16 occurrences failed to note the subtle feedback. 4/5 times the subtle feedback related to the inner panels. Visual information did make the subtleties easier to perceive.

Interpretation

An interesting alternative interpretation surfaced while testing. Despite the explanation of the feedback (communicating surrounding traffic), three of the eight participants interpreted the feedback as a sort of navigation. Instead of moving away from the expansion in the grips, they considered that experience as an opportunity to go. In other words, the feedback pulled them in instead of pushing away. Resulting from this mental model, those participants thought traffic nearing from behind meant they had to brake, because it felt like the grips pushed them back. Interpreting the

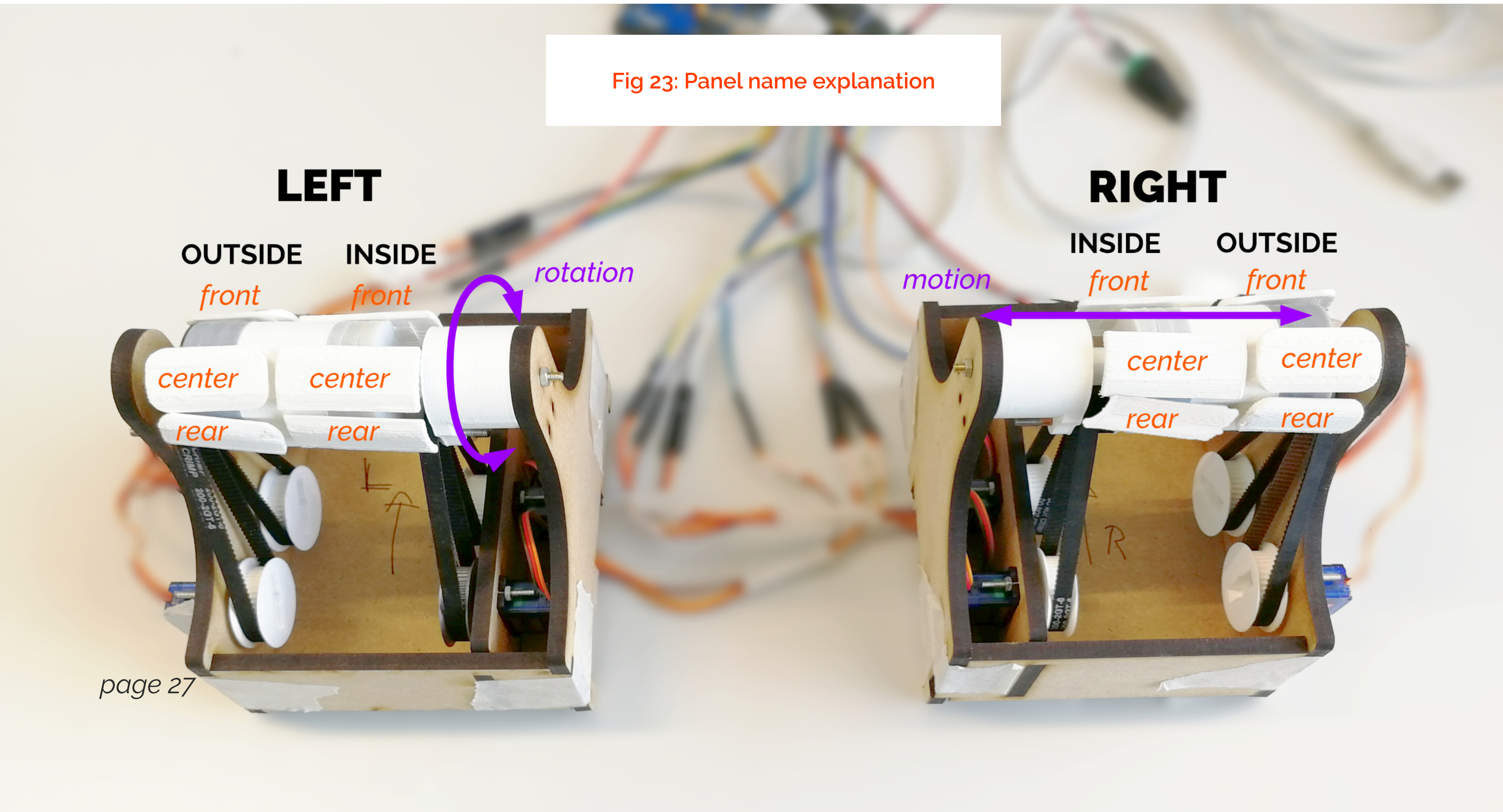


Fig 23: Panel name explanation

feedback this way would therefore result in completely wrong reactions, introducing additional danger instead. However, once the visual information was provided too, the feedback was interpreted as obstacles.

Here too, the scores from table 1 are quite poor. Interpreting the feedback was observed to be much more difficult than perceiving the feedback, as was mentioned by participants many times, for the blind scenarios. However, when considering the "partially correct" scores too, the interpretation scores are much better. Partially correct, here, means when participants pointed out the general location and direction of surroundings, but incorrectly mentioning some details, such as a vehicle that moves from left behind you to the center instead of left all the way to the right (fig 24). This would mean a vehicle should be expected on the right when it is actually behind you.

Scenarios where the haptic feedback was initially perceived poorly, were also interpreted poorly (scenario 4, 5, 7 & 9). This is no surprise considering participants were instructed to blindly interpret what they felt. Nevertheless, despite the difficulty participants had describing the situations in detail, they were able to point out where surrounding vehicles were going roughly (e.g., behind, left, right, in front).

When panels pushed with more force, speed, or "punch" (rapid increments of expansion), this was considered a more dangerous situation as it attracted more attention according to the participants. Panels on the inside, when explicitly perceived, were linked to nearby traffic. Although, they were not always considered dangerous as their motion was too subtle, according to three participants.

Two participants felt an interrupted motion, i.e., not one continuous motion, but multiple separate ones instead. In both cases, this experience was linked to multiple vehicles nearby.

Finally, over time participants became more certain and quicker in blindly interpreting the feedback. Five participants mentioned that it requires some time to learn the patterns. In combination with the visual information, all participants were better at mapping the shape change to the situation and pointed out more details in the feedback.

Usefulness

In terms of usefulness, six participants argued too much information was being communicated. Feedback informing about visible traffic, i.e., in front of you, is not necessary (mentioned by 5 participants), and focus should be on

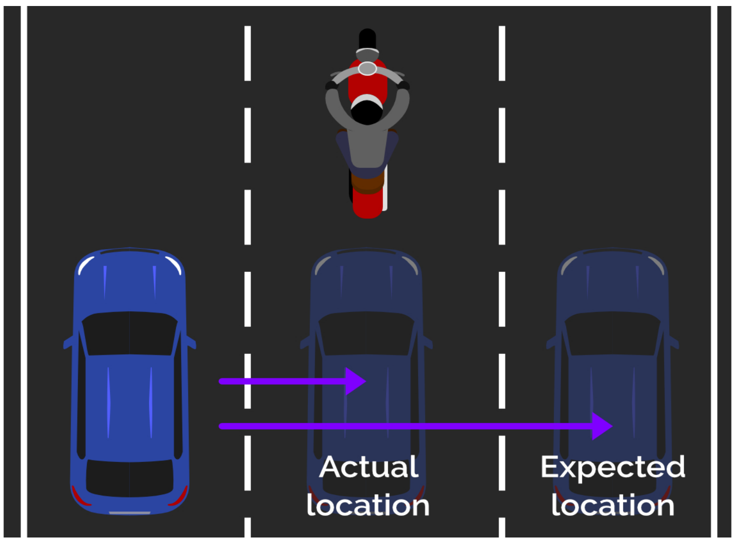


Fig 24: Incorrect interpretation due to incomplete perception of outside panels

communicating warnings (mentioned 6x). These include traffic in your blind spot/behind you (mentioned 6x), vehicles cutting you off at intersections, roundabouts or when merging on the highway (mentioned 5x), vehicles approaching with a large speed difference (mentioned 4x), and nearby vehicles (mentioned 3x), which is especially useful when lane filtering in traffic jams. As described in the interpretation section, for informing (e.g., blind spots) subtle feedback was considered appropriate, whereas immediate danger should feel more aggressive (mentioned 4x).

Conclusion and design implications

The experiment shows the potential to embody surroundings through haptic stimuli in a consistent manner in terms of location and direction, which would already improve a user's situational awareness. Especially with (visual) context to fill in the details that were missed or misinterpreted during the test. However, interpretation without some form of (visual) context proved to be difficult, especially when the feedback becomes more elaborate and rapid. Based on these results and the follow-up discussions with participants, it would make sense to limit the informing feedback to traffic behind you and in your blind spot, and large speed differences as these do not require immediate action. Warning feedback should include nearby traffic and traffic that is on a path intersecting with your own, i.e., being cut off at intersections, roundabouts or merging lanes.

To communicate vehicles moving from left or right behind you to straight behind you more clearly, instead of moving from one side to the other, the inside panels can be emphasized by first expanding the related side to a limited extent (e.g., 70%) when a vehicle moves from beside to behind (see fig 24), followed by expanding them fully together with the other inside rear panel. Doing so put more emphasis on both inside panels, as they move to their final position together.

The front facing panels should be omitted, because those panels communicate less important information about already visible traffic, and the aforementioned information can be communicated through only the rear and center panels. This will probably also make perceiving and interpreting the panels easier as there is less information to process. In addition, the center and rear panels can be spaced better for clearer distinction between rear and center feedback. The rear panels should be rotated forward for better contact with the hand. Informing feedback and warnings can be distinguished by their subtlety, with informing stimuli being smoothed out and warning stimuli being quicker, more forceful, and include small stepwise expansion to mimic vibration, because these were interpreted as more dangerous situations by the participants (figure 25). The design implications are summarized in figure 26.

Finally, it seems like the grips do not attract attention to the hand, but to the spatial situation, as participants tried to imagine what the feedback meant as they felt it. However, since there was no way for the participants to act on the feedback, this can only be assumed until further testing.

The design implications are used to refine the design and prototype in the next iteration. There, the refinements will be tested to validate their improvement on situational awareness and reaction time.

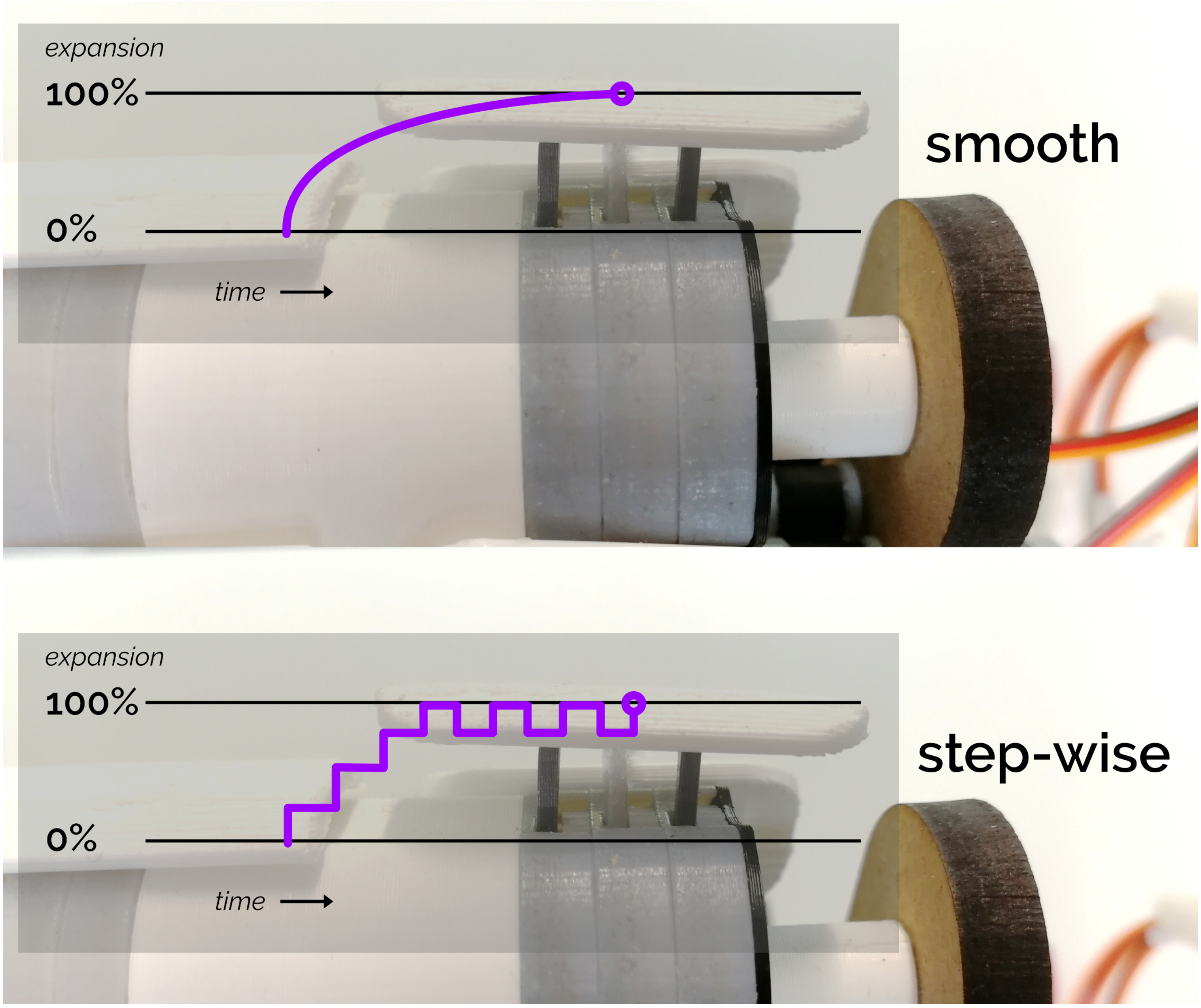


Fig 25: Motion of smoothed out motion vs. step-wise motion, mimicking vibration

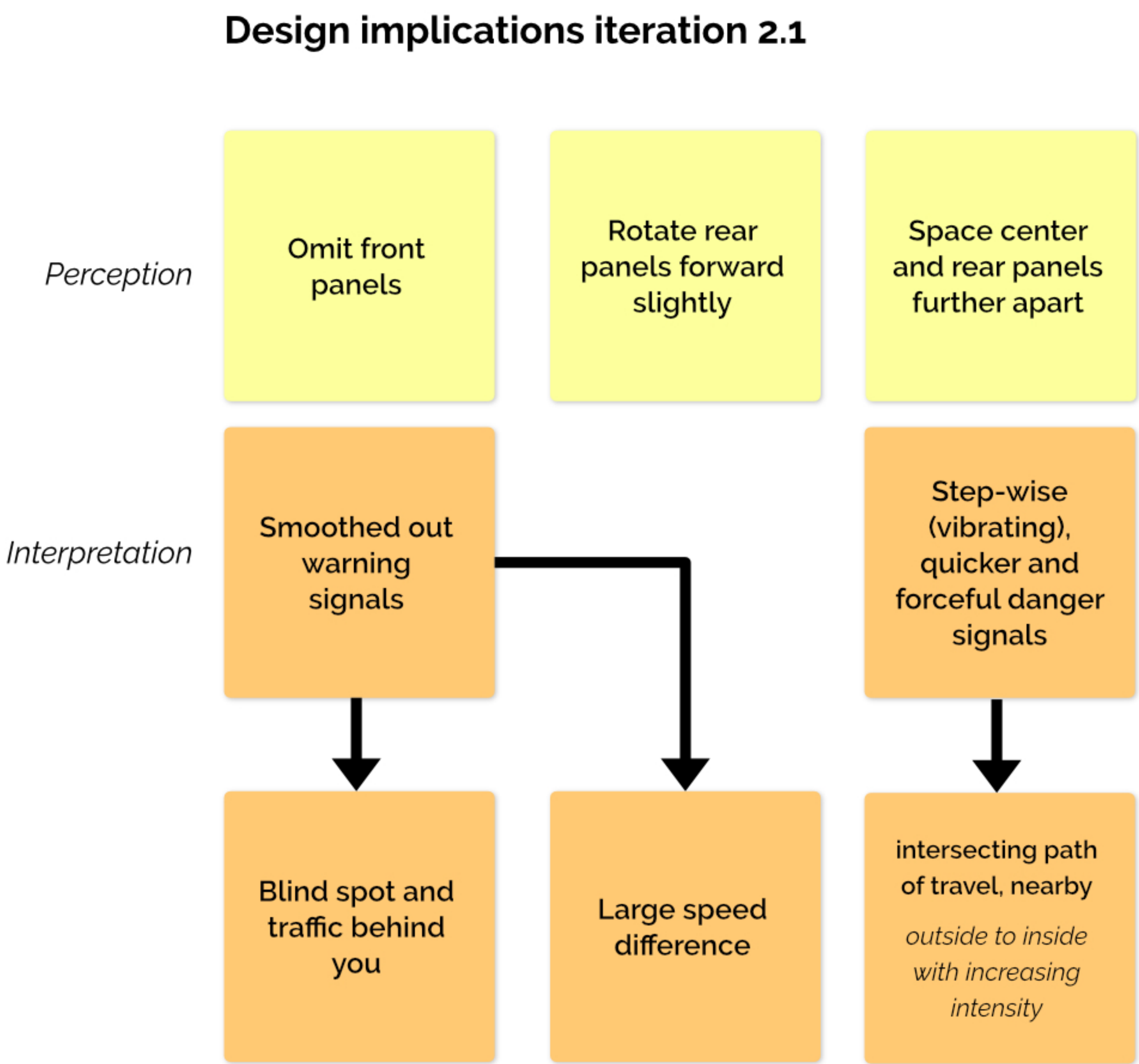


Fig 26: Summary of design implications of iteration 2.1

Iteration 2.2 - Shape change in context

Refinements in haptic stimuli

A report on haptic feedback used in automotive applications provided some key insights and recommendations applicable to the design of InForm [32]. Relevant implications from that report are described here. Firstly, the paper distinguished four classes of tactile stimuli, with increasing levels of attention (LOAs): (a) ignore, (b) change blind, (c) make aware, and (d) demand action. The relevancy of the classes for the grips will be explained next.

The first results from environmental noise, such as wind and engine rumble. These stimuli are ignored (a) while riding. The haptic stimuli present in the grip should be clearly distinguishable from the environmental stimuli, otherwise it will be ignored.

The second relevant class is making aware (c) using stimuli with low to medium vibration amplitudes and continuous motion. This is to support more nuanced information and lower the triggered level of attention (LOA) [22,32]. It also prevents annoyances resulting from constant feedback when it is smoothed out. This is valuable for informing feedback, which occurs relatively regularly. This class of stimuli is in line with the experiment results that suggest smoother and slower shape change for less dangerous situations.

The third stimulus is the demand action (d) class, relevant for warning signals. These move with higher vibration amplitudes and respond more rapidly, like a binary off-on transition, to quickly direct attention and distinguish from informing feedback [22].

Humans are sensitive to vibrations, especially the location and amplitude [18]. These elements can be used to help locate a hazard and achieve a high LOA, as was also suggested in the experiment with rapid incremental motions mimicking vibrations. The location of such feedback would be determined based on the location of the danger, e.g., merging collision hazards would move from outside to inside rear with increasing expansion and step size. Once a panel reaches its max expansion, it will start vibrating by stepping in and out rapidly.

The unused class, change blind (b), refers to notifications that requires no immediate action, but aims at evoking an action in the longer time, such as changing driving behaviour [32]. This could be applied for informing situations such as communicating a "feedback pause" when driving past a traffic jam, to prevent a cry-wolf effect.

Contextual influence on tactile experience

Where the previous iteration evaluated the mapping between feedback and environment in a rather static way, the objective of this iteration is to implement and test the refinements resulting from the prior iteration. The refinements are based on the results from the "perception and interpretation" experiment and literature about tactile stimuli [18,22,32]. These include the number and location of panels, the shape change intensity (speed, force, and amplitude) for informing and warning signals, and the amount of information to communicate in general. The validity of the prior experiment can be questioned due to the gap between provided context (top-down animation) and real-life experience. So, to gain a more valid result, the final experiment will include a simulated context, where the participants experience the improved grips from an interactive first-person perspective. A more realistic context provides information, which in reality would be accessible too. Hence it makes sense to test the shape change in combination with richer contextual information. The central question here is whether the refined patterns are perceived correctly and are meaningful when the environment becomes more immersive.

Unconsidered scenarios

The scenarios listed in table 3 were not yet implemented in the previous experiment, and therefore not tested, because they are special cases with respect to the feedback. Prior results and discussions did already highlight the potential information overload for busy traffic situations and traffic jams. However, completely turning off the feedback might not be the best solution, as it would be difficult to grasp whether the system is still working. Also, it would hinder the adoption of the tactile experience as part of the motorcycling experience as a whole. Some of the scenarios require some form of identification (e.g., using image recognition AI) for adjusting the feedback to better match with the scenario. To evaluate critique on anticipated feedback for busy scenarios and test the proposed feedback adjustments for some other scenarios, a selection is included in the next experiment. This selection is based on the scenarios that caused most concerns about potential information overload in prior tests, while balancing these with the available skills and tools for creating the simulated context, which is described next.

Table 3 - Unconsidered scenarios

Scenario	Included in next experiment	Proposed feedback adjustments
Traffic Jam	Yes	Subtle informing feedback, but warning feedback for lanes changes
Roads with multiple lanes and the same speed	Yes	Subtle informing feedback, but warning feedback for lanes changes
Stopping on a busy intersection with multiple lanes	Yes	
Combinations of multiple situations (with varying danger)	Yes	
Traffic jams lane filtering	No	Feedback tells you whether you'll fit in between two vehicles (intensity range is re-mapped to be closer to the motorcyclist)
Roundabouts	No	
Parked cars at the side of the road	No	Determine speed of other vehicles and obstacles, and if it is stationary, ignore it. E.g., using a time-of-flight sensor. With the exception of stationary obstacles right in front of the sensor (as with a traffic jam). Here, provide feedback when the stopping distance becomes close to free distance.
Bicyclists	No	

Prototyping

To test the refinements, the prototype needed to be modified. Fortunately, the existing prototype was made in such a way that it can be adjusted rather than making a new prototype from scratch. One downside to this approach is that the location of the panels cannot be changed. However, since only four of the six panels per grips will be used, the grips can be turned around, which essentially moves the rear and center pointing panels further apart, as intended. Furthermore, the panels were attached on a single arm, making them quite flimsy. To make them sturdier, and move in a straighter line, additional guides were included (fig 27).

A third improvement on the prototype is increasing the clearance between the timing belts attached to the servos. These are placed further apart by using a longer shaft attached to the small pulley (fig 28).

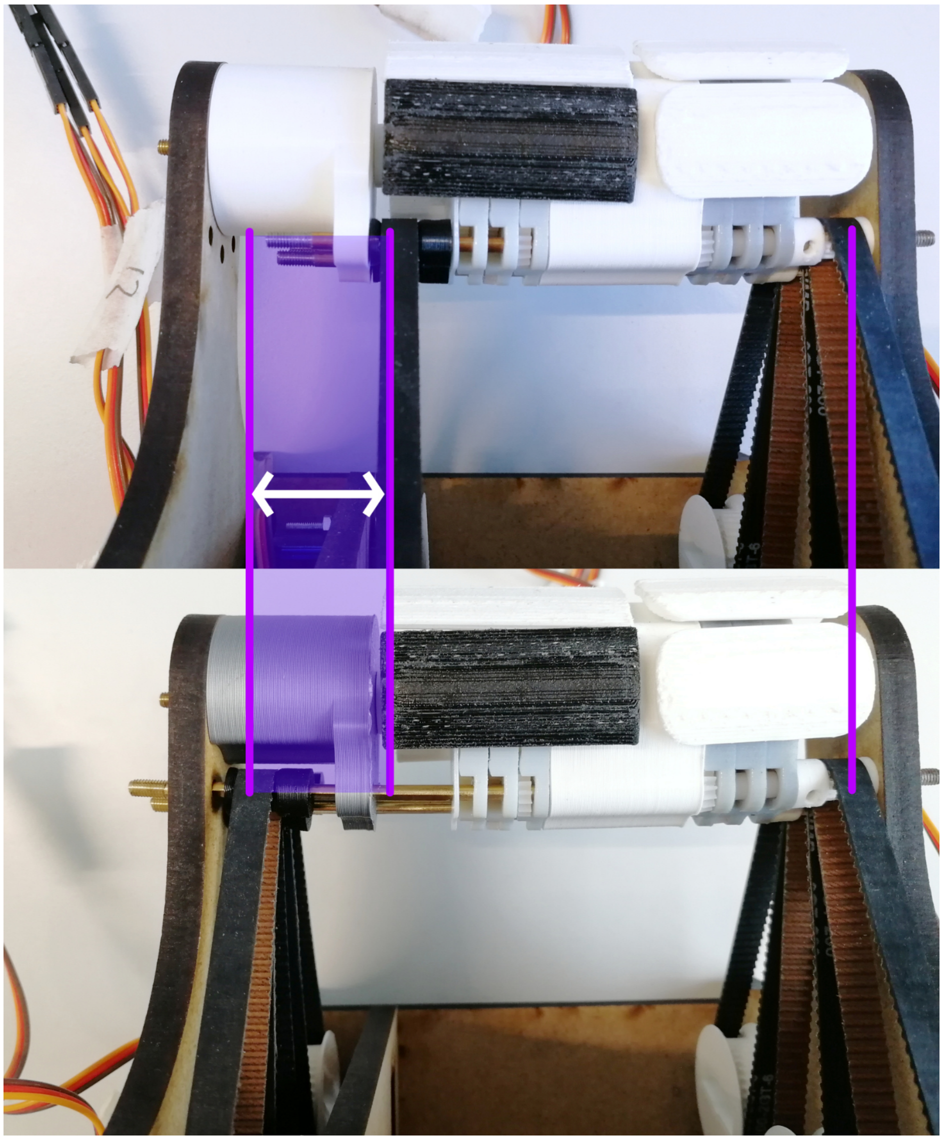


Fig 28: Increased clearance in between timing belts due to extended D-shafts.

Fig 27: Additional guides for the panels to constrain rotation

The bigger prototyping task for this iteration is building the simulation environment, which was made in Unity with C#, and with help from Joris Lodewijks, a master student with great proficiency in Unity. A particular issue would be latency which would make the virtual reality (VR) experience very confusing. Hence only low poly models are used, which require a less powerful computer to render. To view the VR environment, the HTC Vive VR headset is used (fig 29 and 30).

Inside Unity, ten areas are checked for overlap with vehicles. Eight of these areas are linked to one of the eight remaining panels, and two additional areas represent vehicles far and close behind you (fig 31). These areas are similar to those determined in iteration 2.1 and existing blind spot sensors, but these are more precisely adapted to the shape change of eight panels rather than a warning light. Vehicles surrounding the motorcyclist trigger a "smooth" expansion of the outside panels and vehicles closing in on the motorcyclist trigger a "rough" stepwise expansion mimicking vibration to attract more attention [18,22]. The amount to expand depends on the ration a vehicle is overlapping an area. For the inside rear panels, the highest value is used to control the shape change in case contradictory or overlapping values are sent (e.g., a vehicle in area 8 triggers both inside rear panels, while a vehicle in area 3 or 7 only triggers one side. In case both areas are overlapped, the highest values are used, resulting in both inside rear panels expanding).

To account for the misperception of the panels moving all the way from one side to another, while they're in fact pointing straight back (as was found in the experiment of iteration 2.1), individual rear inside panels are limited to 70% expansion, so they can reach 100% only when moving together, emphasizing their direction (pointing back). This is achieved by scaling ratios from the related area in unity (between 0.00 - 1.00) to 0.00 - 0.70. The area linked to both inside rear panels was not scaled, and additionally moves stepwise instead of smooth to attract more attention.

Fig 29: HTC Vive headset

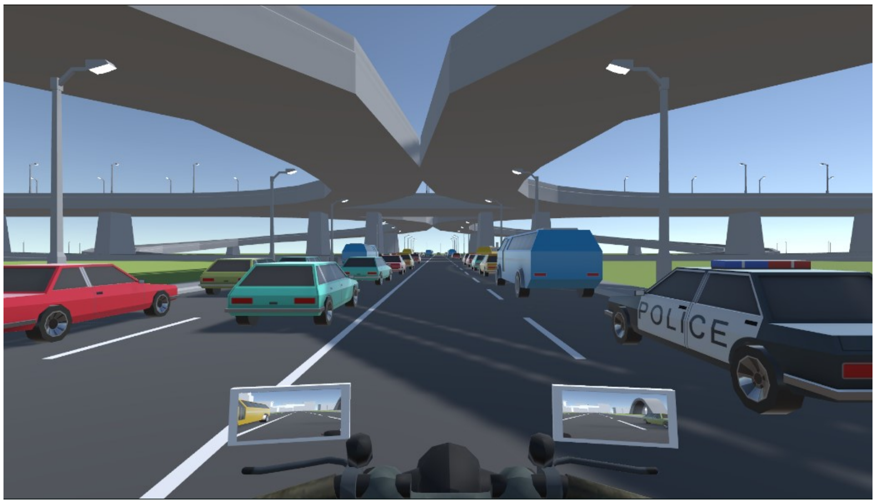


Fig 30: View from VR headset in Unity environment

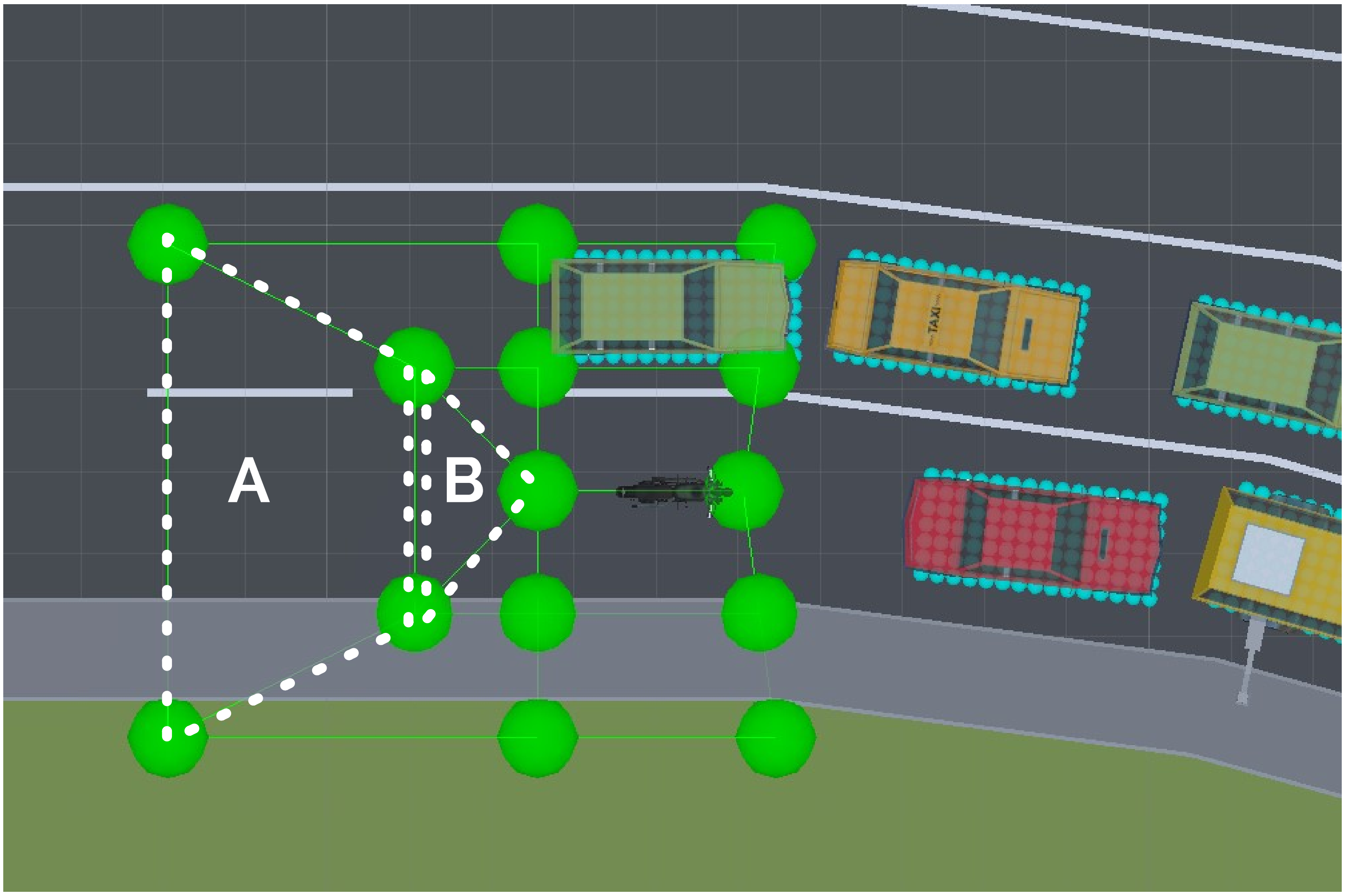


Fig 31: Ten "sensor" areas and points used to determine surrounding vehicles in the Unity environment. The areas marked with A and B move both rear panels smoothly and step-wise, respectively.

Method - Iteration 2.2

This method was evaluated by a PhD student with an expertise in intelligent vehicles.

Objective

The goal of this experiment is evaluating if the refinements of the prototype improve the perception and interpretation of the feedback, and if the less elaborate selection of feedback provides (more) useful information for motorcyclists. A set of sub-questions relevant for this iteration include:

1. *How to balance the importance of warning feedback when more hazardous events take place simultaneously?*
2. *What is the effect of the haptic stimuli on reaction distance?*
3. *When to provide feedback considering both reaction time and information overload?*
4. *How will different feedback states (haptic patterns) per hand be experienced?*
5. *How will multiple feedback states or transitions at once be experienced?*

Participants

Five participants (n=5) and a pilot were recruited based on having a motorcycle license or taking lessons. The participants were aged between 16 - 35 with 1 - 3 years of experience. All participants rate their skill level between beginner (= 1) and moderate (= 4) (on a scale of 1 - 9). Both male and female participants were included.

Participants are recruited via a personal network in the motorcycle community, but unacquainted with the researcher. The study was ethically approved with an ERB form, and before conducting the test participants gave their written consent for participation and data collection using a consent form.

Materials

The experiment uses a first-person virtual reality (VR) setup in Unity in combination with the improved shape changing prototype. The environment consists of a (first person) motorcycle with working mirrors, a set of roads and intersections, and other vehicles. Again, multiple scenarios are made that allow to test a broad, but controlled variety of situations and answer the (sub)questions. The scenarios include one or more vehicles surrounding the motorcyclist, which all move according to a predetermined path (including the motorcyclist). For a more realistic experience, the individual grips are mounted onto a bar that constrains their movement and mimics a handlebar. A set of headphones are used to mute the noise from the servo motors, as these might influence the perception of the feedback (hearing but not actually feeling the feedback) and distract from the environment. To record the data, a video camera and a worksheet are used (fig 32).

Fig 32: Experiment 2 setup with the VR environment.

Procedure

This experiment does no longer include a "blind" round as that would diminish the added value of the VR environment. Instead, this experiment exists out of a round with -and without tactile feedback in order to test the effect on reaction time, although to a limited extent.

Before the test rounds, participants are familiarized with navigating in a VR environment. An introductory scenario is run, without tactile feedback, to mitigate the impact of lacking experience with VR. During this phase headphones playing common traffic sounds are used. Participants that experience nausea, dizziness, or any other form of discomfort due to the VR environment are excluded from testing.

The remaining participants are divided into two groups. One experiences the "with feedback" round first, the other the "without feedback". Scenarios are randomly selected to minimize effect of following a predetermined order. For each scenario (see table 4) participants are asked to think aloud [25] about what they're feeling and seeing to gain insights into their momentary experiences.

Table 4 - Scenarios used in experiment 2

Scenario	Description	Dangerous vehicle for quantitative measurement
1	Cars braking in front of you, car behind you stops really close to you	car behind you
2	Bus passing on the left, car illegally overtaking on the right	car on the right
3	Driving past a traffic jam when suddenly a car from the left comes out into your lane in front of you	car on the left
4	Bus overtaking really fast from the left	bus on the left
5	Bus drives up to your left blind spot while a car at the right overtakes illegally	car on the right
6	Driving in between multiple vehicles at roughly the same speed	no real danger
7	Stopping on a busy intersection with multiple lanes, while a car drives up closely from behind	car behind you

Each round (i.e., with -and without feedback) has similar, yet different scenarios to avoid participants recognizing a scenario and reacting based on memory. During the scenarios, participants are observed in terms of when and where they look in the VR environment. To collect a quantitative measure of the effect on reaction time, participants are prompted to describe the surroundings, and mention potential hazards. The quantitative measure will be the distance between a hazardous vehicle and the participant (in VR) at the moment the participant mentions the hazard. The distance is read from the Unity interface after the researcher pressed the space bar to reveal the distance (only visible to the researcher). These are compared to reaction distances without tactile feedback. However, since the prototype is limited in terms of interaction, the type of reaction (i.e., braking, swerving, etc.) cannot be tested yet.

After each scenario they rate the danger and intensity of the feedback on a Likert scale, from 1 - 5 (completely safe - extremely dangerous, and extremely subtle - extremely aggressive, respectively). These scales give insight into the subjective perception of danger and whether the feedback intensity matches that danger. Finally, each scenario is briefly discussed for gaining a more complete image of the participant's experience.

Data collection

Data is collected by audio and video recording the user and the computer display that mirrors the participants view in VR. The distances are documented per round, participant, and scenario. The provided worksheet is used by participants to rate the danger of a scenario and the intensity of the feedback on a Likert scale (1 - 5). Finally, observation and discussion notes are made during the study.

Analysis

For analysis of the qualitative results, again a thematic analysis is conducted, similar to the pervious test. This time with a focus on more specific traffic situations, the experience of combined and varying feedback per hand, the balance between varying danger levels simultaneously, and evaluating what amount of information is still useful before it becomes confusing.

The quantitative measures test how well the feedback intensity is balanced with the hazards, as experienced by the participants by using the Likert scales. Additionally, the effect of the haptic feedback on reaction distance is compared to similar scenarios without feedback. This provides some insight into the effect of the grips on reaction time/distance.

Results and discussion- Iteration 2.2

Before conducting the test, a pilot study was performed on half of the scenarios. The pilot indicated the need for some additional hardware such as a wireless keyboard and extension cord. The results are described in terms of quantitative and qualitative results, each focusing on different (sub)questions. For some qualitative results, the pilot study is separately reported, as this sometimes yielded interesting insights. However, the pilot results are not considered for the overall conclusion and quantitative measures.

Quantitative results

FEEDBACK MATCHING DANGER

The first quantitative measure compares the danger of a scenario with the intensity of the feedback as perceived by the participants. This gives insights into whether the feedback is appropriately communicating the danger of a situation. Table 5 shows the differences in danger rating for the two rounds of similar scenarios. The positive numbers show that each scenario without feedback was considered slightly more dangerous, with a relative peak (scale = 1 - 5) for scenario 5. This data is useful for interpreting the effect of feedback on reaction distance.

Table 6 shows the difference between the perceived danger and feedback intensity for the "with feedback" round. This shows that Scenarios 6 and 7 do not match well in terms of feedback and danger level. Interestingly, Scenario 3 has both the highest perceived danger and best-balanced feedback intensity. However, it should be noted that the high feedback intensity did have too little contrast to point out the dangerous situation of that scenario. This is because all vehicles were close by, but did not pose a danger, except one. In other words, the danger was not balanced with (most of) the feedback, despite the positive looking numbers.

Table 5 - Difference in mean danger for 'with' and 'without feedback' rounds

Difference in mean danger round 1 and round 2 scenarios

	sc 1	sc 2	sc 3	sc 4	sc 5	sc 6	sc 7
	0.2	0.2	0.2	0.2	0.6	0.2	0.2
Mean danger rating (without feedback)	3	2.4	4.4	1.2	3	2	2.4
Standard deviation (without feedback)	0.6	1.2	0.8	0.4	0.9	1.5	1.4
Mean danger rating (with feedback)	2.8	2.2	4.2	1.4	2.4	2.2	2.6
Standard deviation (with feedback)	1.0	1.0	0.7	0.5	1.0	0.7	0.8

Table 6 - Difference in mean danger level and feedback intensity of feedback rounds

Difference in mean danger level and feedback intensity

	sc 1	sc 2	sc 3	sc 4	sc 5	sc 6	sc 7
	0.2	0.4	0	0.2	0.2	1	0.8
Mean intensity rating (with feedback)	2.6	2.6	4.2	1.6	2.6	3.2	3.4
Standard deviation (with feedback)	1.0	0.8	0.4	0.8	0.8	0.4	0.5
Mean danger rating (with feedback)	2.8	2.2	4.2	1.4	2.4	2.2	2.6
Standard deviation (with feedback)	1.0	1.0	0.7	0.5	1.0	0.7	0.8

Most other scenarios were rated with neutral danger values (2 - 3), while other vehicles did come close by causing relatively intense feedback (as is also visible in the ratings). Participants indicated to find the situations not that dangerous since the speed difference was not particularly high and they saw the dangerous vehicles early. This not only explains the mismatch in feedback intensity, but also suggests that speed difference is more important than distance.

EFFECT OF FEEDBACK ON REACTION DISTANCE

The second quantitative measure looks at the difference in distance for noticing a hazard. Table 7 shows the difference in distance between the "Player" and "Vehicle" at the moment of noticing a hazard. The "NaN" values mean that in one or both scenarios, a participant did not point out a hazard. Negative (green) values mean a participant noticed a hazard sooner with the feedback.

The slight differences could be the result of similar, yet different scenarios. In addition, Scenario 2 has both a large positive and negative value, meaning that the participant had more influence than the feedback on that result. Interestingly, most values are negative, suggesting a slight improvement in reaction distance with feedback, except for scenario one, which scored significantly better without feedback. Again, this could be the result of the difference in scenario making hazards easier or more difficult to spot.

However, the larger values (i.e., quicker reactions) of Table 7 should be used carefully, as the feedback only triggers 3 units from the side, and 6 units from the rear of the Player (with a max range of 6.7 according to the Pythagorean theorem), meaning that everything beyond that range (orange highlights in table 8) was noticed without experiencing the feedback. This means that only Scenario 3 presents relevant results. In this scenario (a traffic jam), many vehicles surrounded the Player, therefore, spotting one single vehicle as a hazard becomes a much more difficult task. Notably, all of the values are negative, indicating a quicker reaction distance for this scenario. The small values are the result of nearby traffic in that scenario. What's more, in busy traffic, the feedback is significantly more valuable.

Table 7 - Difference in distance in with and without feedback *(1 unit ≈ 1 meter)*

sc 1	sc 2	sc 3	sc 4	sc 5	sc 6	sc 7
NaN	3.4	-2.1	NaN	-8	NaN	NaN
-1.5	-2.5	-1.8	-6.7	-7.5	NaN	-1.2
18.7	16.8	-3.8	-19.4	-14	NaN	-4.4
17.7	-2	-2.3	-0.5	-9.8	NaN	1
NaN	-24.5	-2	-4.1	2.6	NaN	NaN

Green = with feedback was faster response (in distance)
Blue = without feedback had faster response (in distance)

Table 8 - Distance of noticing hazards before feedback activation
(1 unit ≈ 1 meter, orange is further than feedback range)

sc 1	sc 2	sc 3	sc 4	sc 5	sc 6	sc 7
no danger	8	5.3	no danger	10	no danger	no danger
4.7	7.9	4.7	15	11	no danger	4.7
8.3	12.6	6.7	19.4	7.6	no danger	4.4
6.9	4.8	5.1	3.3	14.8	no danger	2.8
no danger	11.6	4.8	11.3	5.5	no danger	no danger

Qualitative results

The qualitative results can be divided into two groups. One being the effect of the feedback and the other the implementation of the feedback.

EFFECT OF THE FEEDBACK

Regarding the effect of the feedback, the results show that haptic stimuli trigger head checks (checking blind spot by looking over shoulder, a.k.a. shoulder check) by all participants, i.e. they look into the direction related to the hand they felt feedback: "*I'm looking at the bus [on the left], because the left one [grip] is wiggling*" and "*[the feedback] made me look again, or faster and more, when I could feel something happening*" (P4). This resulted in earlier and better detection of vehicles in the blind spot compared to without feedback for all participants.

During the scenarios, all participants were observed to check the mirrors more often without the feedback. Especially in busy scenarios, they were scanning around more. One participant pointed out that without feedback he had a worse overview of the situation and his appreciation of the feedback had grown as a result.

The feedback was especially effective in busy situations and with nearby (fast) traffic, since participants quickly noticed all vehicles in less crowded scenarios. Or as some participants pointed out, the feedback helps to guide your attention when it is divided due to a high number of surrounding vehicles.

On the other hand, incorrect feedback activation caused confusion and distraction, mentioned by 4/5 participants and the pilot participant, as they were seeking a non-existent hazard.

Besides noticing more surrounding traffic, the feedback had a reassuring effect that confirmed the image participants had seen with their eyes: "*what I found really good was the subtle feedback of the blind spot [...] I liked it when something was nearing, I felt its presence*" (P3), "*It is actually quite comforting when it [the panel] is moving, because then I know there are people coming from my right or left. I don't really want to look at it, I just know they're coming*" (P4) and "*that hand was telling me that the car was still ahead, which was a nice thing to have, and it wasn't coming any closer because the intensity wasn't going up, so I had time to look back*" (P2). These experiences also confirm the interpretation of the feedback as obstacles coming closer when the intensity goes up.

IMPLEMENTATION OF THE FEEDBACK

The distinction between inside and outside panels was not consistently perceived. What's more, it did not seem to add valuable information for the participants, especially since warning signals were different in both location (inside instead of outside panels) and haptic stimulus (vibration instead of expansion). All participants mentioned that the expansion alone was clear enough. Especially when the motion was smooth because that made it easier to track the represented vehicle. Whereas the vibrating feedback was considered unclear and distracting as the location of the vibration was difficult to perceive and made participants nervous.

In addition, busier scenarios clarified that the contrast between informing and warning feedback was too small, resulting in feedback "*going crazy*" (P2). The lack of contrast was confirmed by five participants, including the pilot, for example: "*make the different levels of input [feedback] sharper [and] reserve feedback for when you need it*" (P2) or "*it [the vibration] is distracting*" (P5).

Finally, four participants, including the pilot said that frontal and rear feedback is only valuable for large speed differences, similar to the results of the previous test. The vibration/stepwise type feedback was considered most appropriate for such a warning, where it would be used to shift your attention to the front or rear.

Conclusion and design implications

The stepwise motion mimicking vibration was not considered useful, as it caused confusion and distraction. It indeed triggered a high level of attention (LOA), as also indicated by [18,22,32], but it did not direct that attention to a hazard. The smoother feedback was much easier to perceive, also when varying per hand, and allowed for higher contrast for varying levels of danger, which the vibrations did not. This was especially relevant in busier traffic, such as Scenario 3.

The feedback activation distance is too large for busy situations, triggering too often and causing an information overload, but for situations requiring immediate responses, the feedback might be too late. Here it might be useful to consider speed difference as an additional factor for setting the feedback trigger distance. The results show that speed difference is more relevant for determining feedback intensity than relative distance, which makes sense in terms of reaction time, as it (partly) depends on the speed difference.

In addition, vehicles straight behind you are also not considered to be dangerous, as long as their speed difference is within limits. This also goes for vehicles in front of the rider, which was also found in the previous test. Nevertheless, traffic in front of, or behind the rider, can trigger a short set of feedback "punches" to alert the rider if their approaching speed is relatively high. Using this type of feedback in combination with expanding panels for the blind spot simplifies the number of feedback states to make it easier to distinguish and interpret them.

Traffic in your blind spot, that cannot be seen in the mirror was considered valuable by participants, as they noticed vehicles that they otherwise would have missed, or only noticed when the scenario had ended, and they were looking around in the VR space. The feedback was even more valuable for crowded traffic situations, such as traffic jams, where a consistent improvement on reaction distance was observed. In these situations, riders must pay attention to a busy environment, without knowing where hazards may come from. The feedback seems to help locate these hazards when they present themselves, especially when hazards come from outside the focused or peripheral field of vision (i.e., the blind spot).

In other words, it seems that less detailed feedback will yield more usable information, where hazards are communicated through a single "ring" (e.g., 3 panels, rear, center and front) that smoothly follow a vehicle. Nearby vehicles make the expansion larger, large speed differences make the activation range larger, and frontal - and rear collision hazards can be communicated through short "punches" of the panels. If a vehicle from the side comes really close (within your lane), the feedback will vibrate throughout the whole grip on the relevant side, as this was still easy to perceive and thereby attract a high LOA to the hazard. The activation distance for vibrations will be reduced and is preceded by a large expansion. Thus, the vibration feedback functions as a last resort when expanding feedback is not acted upon. This also makes it easier to understand the direction of the hazard, as that could already be felt by the smooth expansion.

Iteration 2.3 – Aesthetics

Before diving into the styling, some observations were made to find out what materials and appearance characteristics are common for designing motorcycle grips. These are listed below and used as a starting point for ideating on grip appearance.

Appearances

- Both simple, and detailed and sophisticated designs
- Most include dampening and/or grippy surface
- Colours are mostly black and silver
- Combined and uniform materials

Materials

- Rubber
- Leather
- Chrome / aluminium
- Foam
- Plastic

Opportunities (see fig 33)

The grips with separate areas of grip material spark the opportunity for moving components within a rigid housing. There are no grips included in the (non-exhaustive) selection that have two "rings" of areas next to each other. Only one, three or four. This resonated with the initial mechanism, however, further in the process, this changed to using the center ring to locate the shape change, instead of two "rings" covering the whole grip.

The appearance, materials, size and features of the grips are all influenced by the application area. That is the type of motorcycle and riding style. A racing motor will have different requirements than a heavy cruiser or a lightweight commuter motorcycle. Furthermore, a matching appearance of the grips depends on the preference of the rider. Hence the large variety.

Chrome with black is common amongst cruiser and retro types of motorcycles, whereas the completely black rubber grips are more common on street bikes, and colourful and grippy grips are more common on dirt bikes. The focus of InForm is on traffic, which rules out racing motors (and their additional safety requirements) and dirt bikes as these are not legal for road use.

Fig 33: Selection of motorcycle grip appearances used for benchmarking style.

This is of course not an in-depth categorization but highlights the challenge for a "one size fits all" kind of grip. The first iteration initiated from a personal preference of traditional cruiser styling, which includes chrome and black, with a hint of colour which was used as a starting point for designing the appearance (fig 34).

For a more universal appearance, a black version is proposed, as this is a common appearance for motorcycle grips. The shape and panel location of the grips was explored, and some details were added to make the grips look more interesting. However, a quick, high-level validation showed that simpler styling was preferred. This validation was done by simply asking motorcyclists to choose a preferred grip and panel design from a set six grips and four panels (see fig 35).

The appearance of the resulting design (fig 36) was inspired by these results, though some of the looks also have a functional reason. The expanding edges of the grip help to locate the edges without looking at your hands. The center ring helps to separate the inside visually and physically from the outside panels in an attempt to make them easier to distinguish blindly. Finally, the panels are made from rubber to both dampen vibrations and provide grip. However, due to the parallel nature of the aesthetics iterations, the requirements of the grips changed over time, and so did the appearance. The final design and its features are described in the next section.

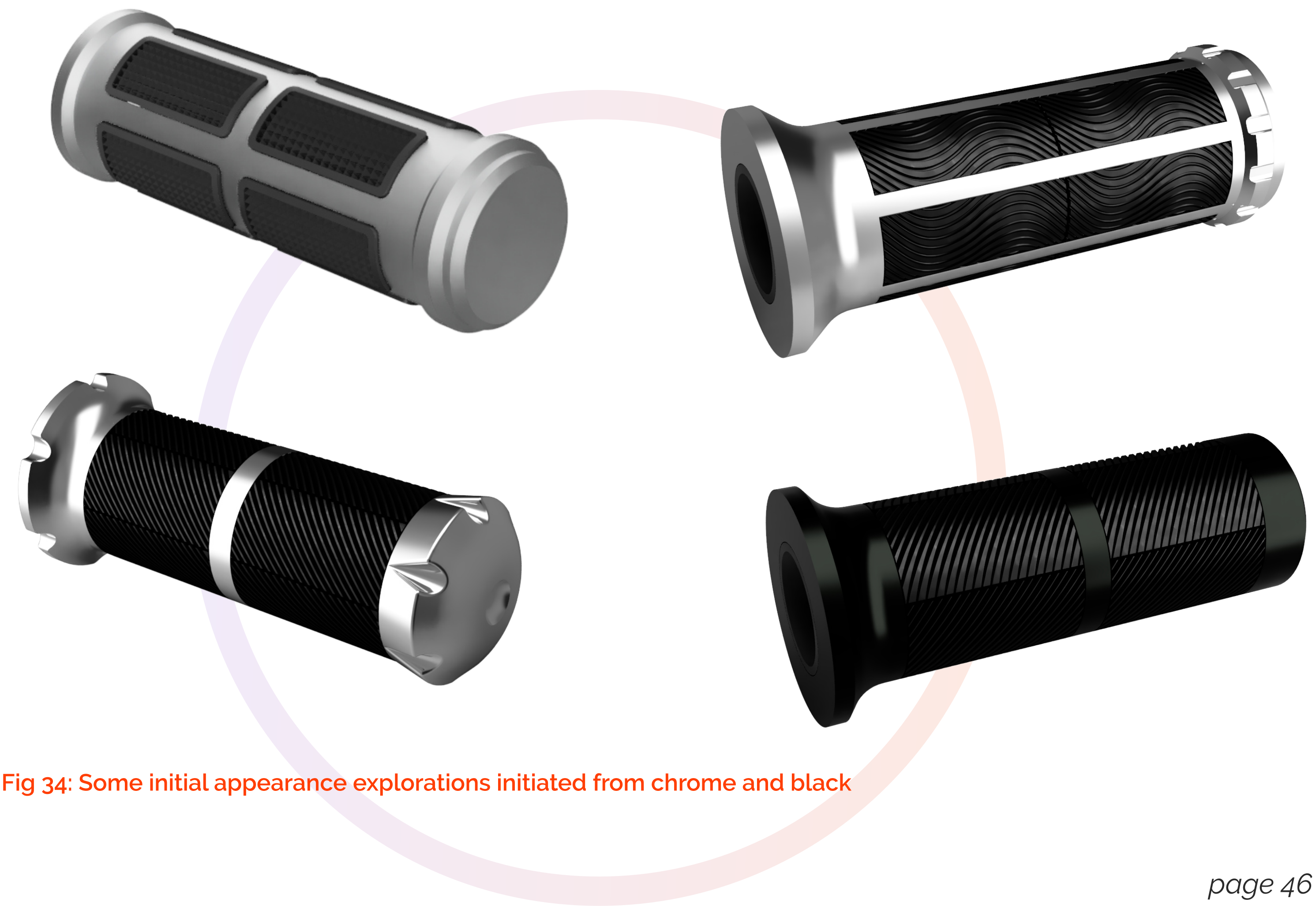


Fig 34: Some initial appearance explorations initiated from chrome and black

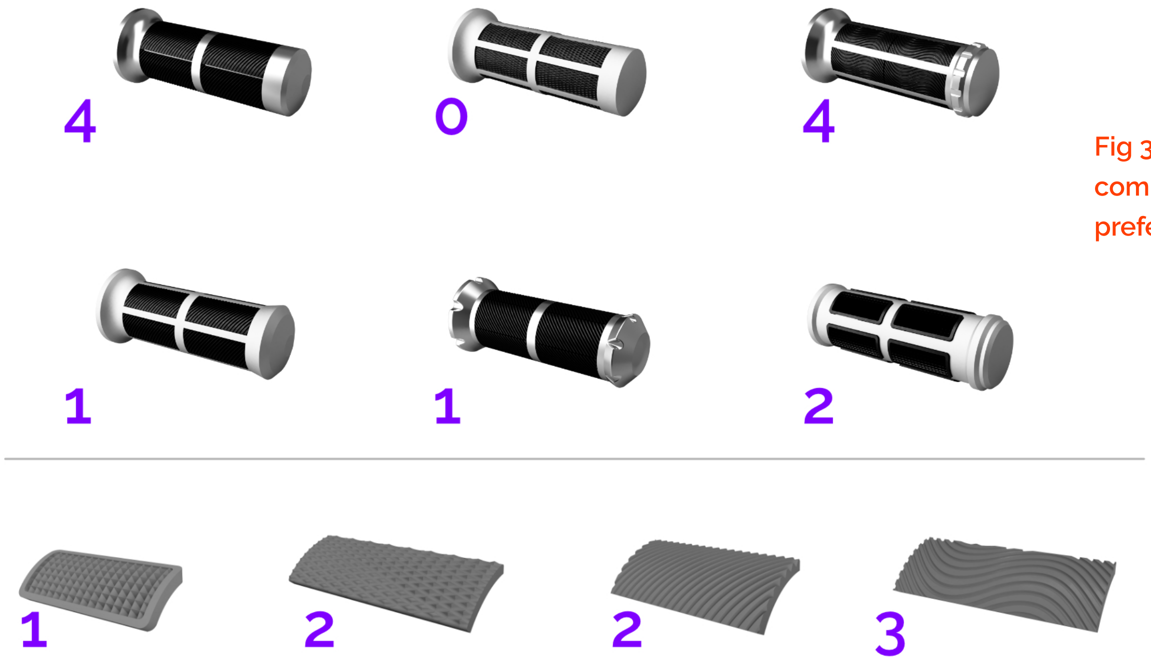


Fig 35: Grip appearance comparison with preference scores.

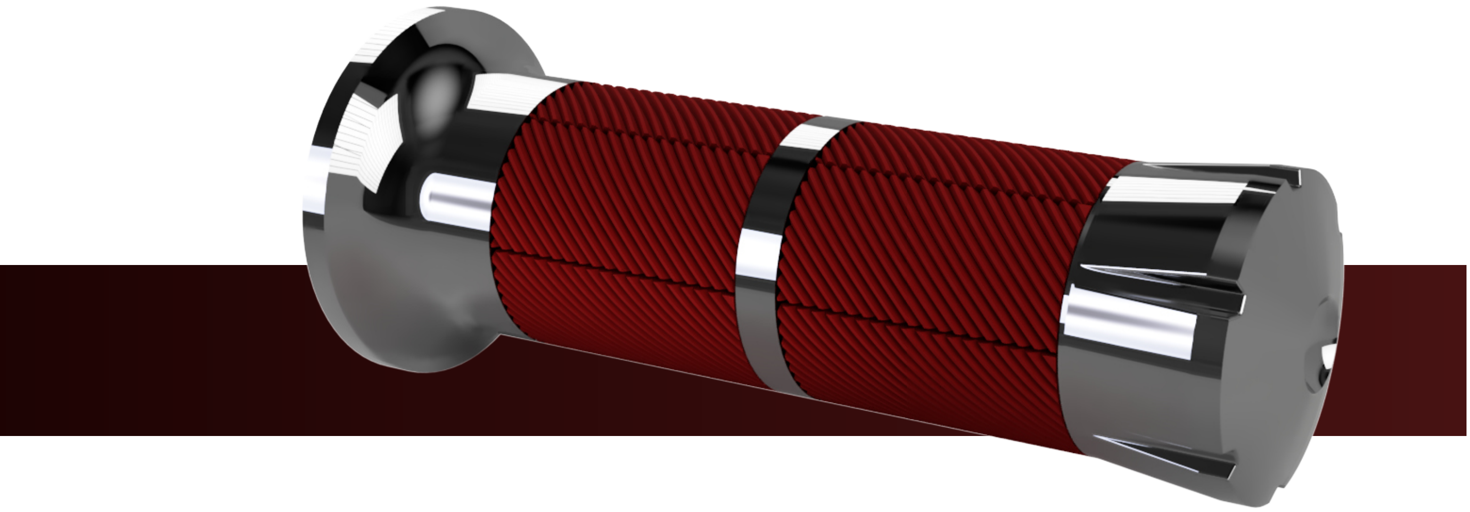


Fig 36: Refined grip styling based on feedback from motorcyclists.

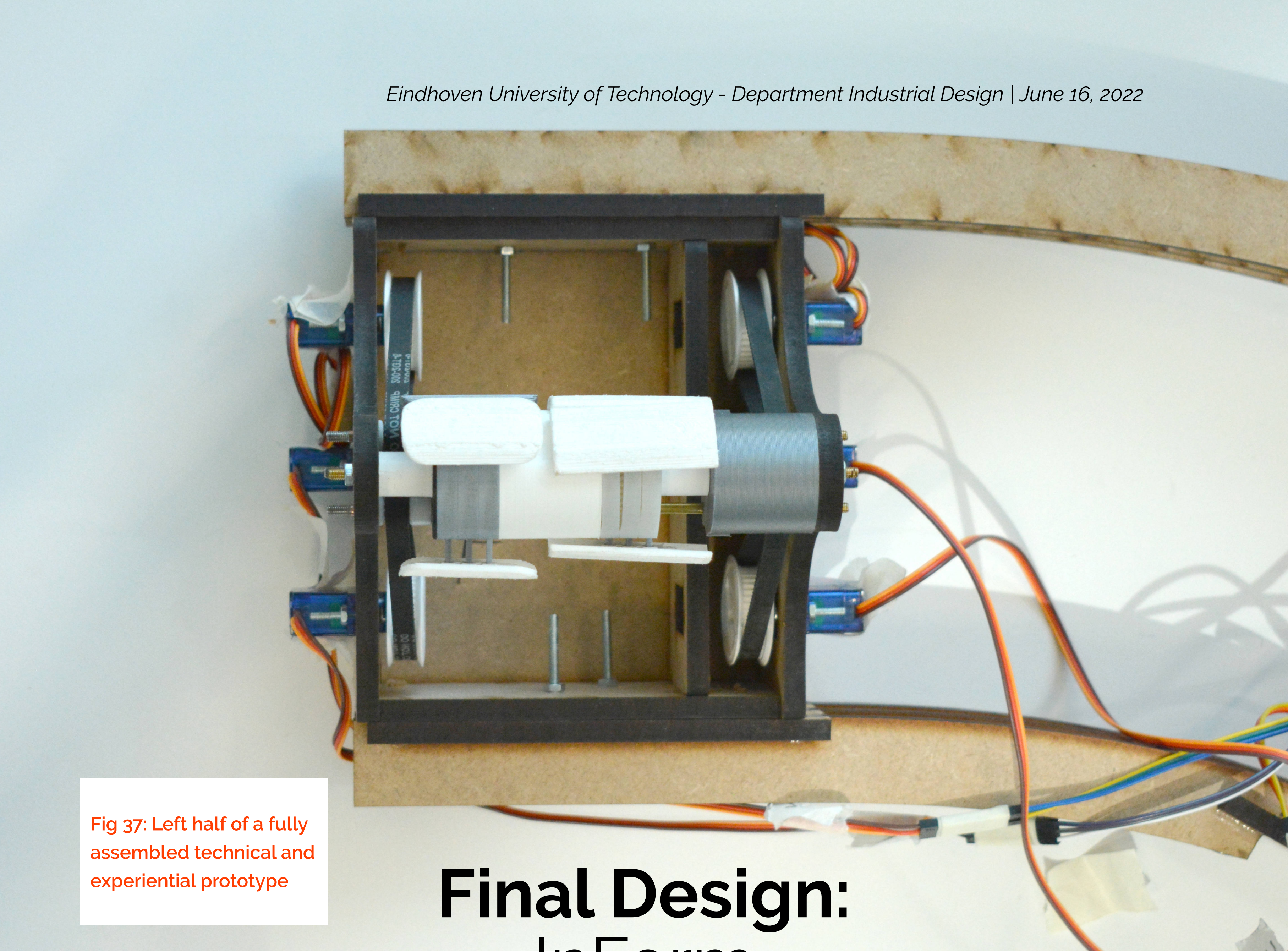


Fig 37: Left half of a fully assembled technical and experiential prototype

Final Design:
InForm

InForm is a set of motorcycle grips that change shape by expanding using two panels and vibrate using a third panel. The shape and vibrations are used to guide a user's attention to potential hazards with varying levels of danger, thereby triggering varying LOAs. This helps to safer navigate through traffic that might not see you.

The final design is mainly experiential and aesthetical, but technically not yet complete, because the design process started from the user/experience side, instead of a technology. This prevents limitations while exploring and testing various designs, as technical feasibility is initially considered less. In what follows, the essential characteristics of the design are described. For details on the technology and realisation of the prototype (see fig 37), I refer to the two prototyping sections of iteration 2.1 and 2.2, as the prototype did not change from a technical perspective (only the experience was modified).

Fig 38: Final appearance of the grips, and some proposed color options, that consider the revised haptic experience requirements.

Physical layout

The test results showed that the inside and outside panels are not well distinguishable while experiencing an immersive context. What's more, this distinction is redundant, as the warning feedback driving the inside panels has changed to vibration, making the distinction in location redundant.

Hence, only three panels per grip remain, with the rear panel pushing on the lower part of the palm, the center pushing right before the knuckles and the front panel pushing near the first joint of the fingers (see fig 38 and 39). The panels both change shape and vibrate depending on the highest danger level.

Instead of the inside-outside division, the panel ring is relocated at the center of the grip, to maximize perceivability with varying hand sizes and holding grips. The former layout made it possible to only touch one "ring" of panels due to their relatively large width. In addition, a centered set of panels allows for easier perception of the absolute expansion with respect to the rest of the grip, which doesn't change shape.

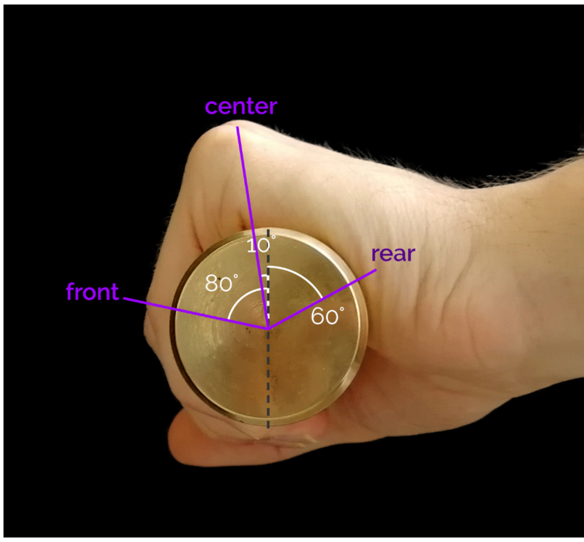


Fig 39: Estimation of panel angles based for optimal distinction of panel location

Feedback mapping to environment

The shape changing feedback is mapped to the environment as shown in fig 40 and 41. Commonly used sensors for acquiring the location of other vehicles are LiDAR, radar and cameras. For example, Bosch Advanced rider assistance systems (2W) [9] uses radars located at the front and rear of a motorcycle (see fig 42). Using a camera seems less useful, as it cannot "sense" through bad weather conditions, such as fog, where frontal and rear collision are even more important warning signals.

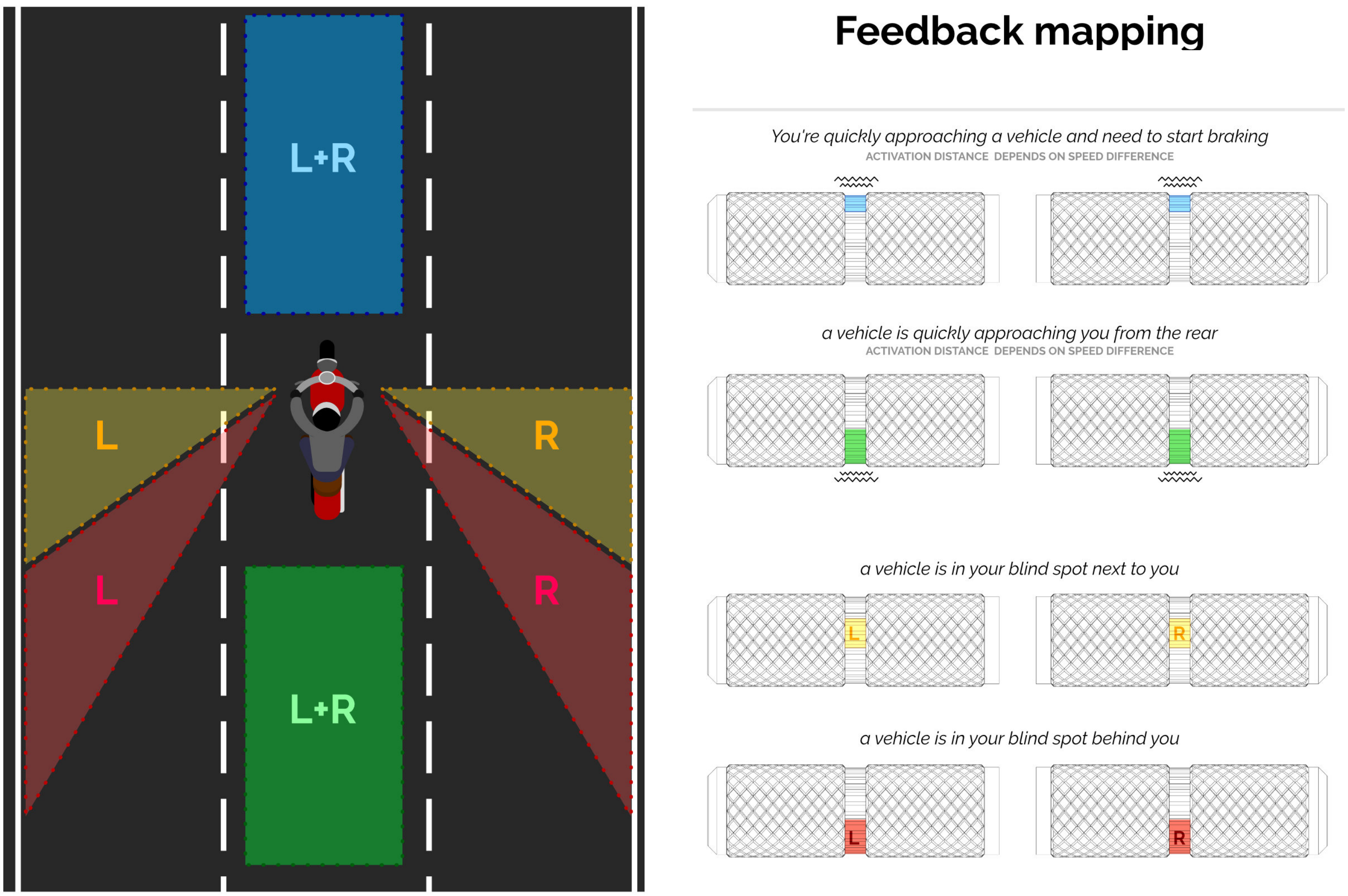
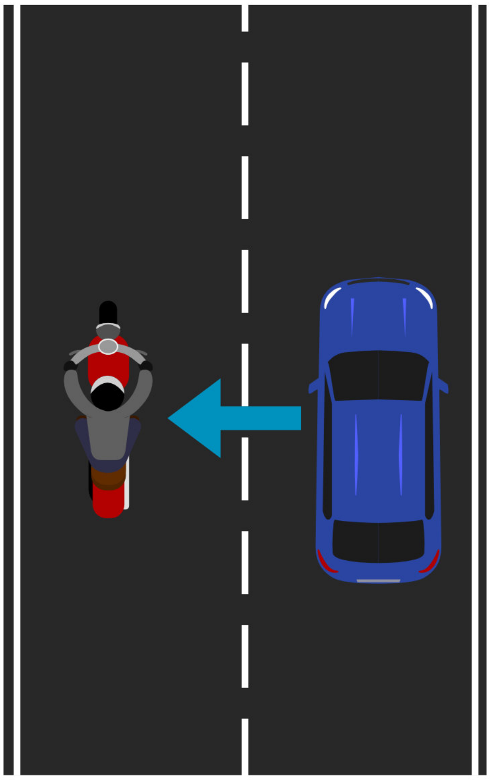


Fig 40: Feedback mapping of collision and blind spot warnings



Feedback mapping

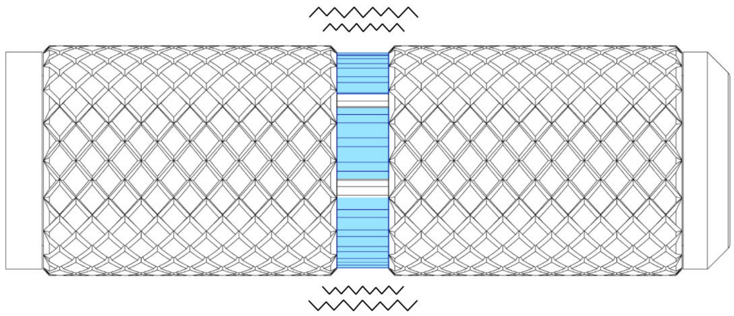


Fig 41: Feedback mapping sideways collision warnings

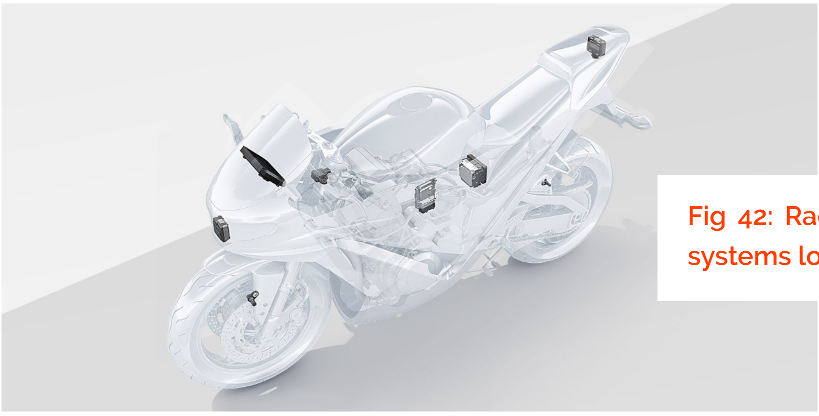


Fig 42: Radars from Bosch Advanced rider assistance systems located at the front and rear of the bike.

Feedback intensity

As was pointed out multiple times by users, glove thickness could impact the perceivability of the feedback. To cope with this, an additional control can be added to set the intensity. Such a control also allows users to turn off the feedback, e.g., for special situations such as going to a racetrack, or off-road riding. Using a set of pre-sets, users can easily judge how high to set the intensity when changing to winter gear. The pre-set intensities do require to be tested still.

Activation range

Throughout the whole design, the feedback activation range is determined by speed difference between the rider and approaching vehicles, as higher speed differences require quicker reaction times, which can therefore be compensated by a larger distance between the rider and the vehicle.

Frontal and rear collision warnings

For traffic approaching with large speed differences in front of or behind the rider, a set of haptic "punches", similar to quick parking sensor beeps, are used. The trigger frequency is determined by the distance and speed difference, as these together determine the danger level. For differences under a threshold value, this feedback won't activate, minimizing redundant attraction of attention.

Blind spot informing feedback

Blind spot feedback will remain to communicate through shape change. The speed difference of approaching vehicles determines the activation range. Additionally, a large difference amplifies the feedback expansion speed, which is co-controlled by the occupation ratio of the blind spot area.

Blind spot/sideways collision warning feedback

To increase the contrast between informing and warning feedback, the range for warning feedback (vibration) is reduced. Vibration only triggers when vehicles come extremely close, to prevent information overload and lack of directional information.

Discussion

Over a one-year design process, two main iterations were completed during which motorcycle grips were designed and tested to improve the safety of motorcyclists without hurting the hobby aspects of motorcycling. The problem this design tries to tackle is the poor visibility of motorcyclists. Continuously informing a rider about their surroundings allows them to react quicker to hazardous situations that often result from this poor visibility. In addition, participants indicated to be reassured by the feedback, as it functioned as a confirmation on their vision.

Through multiple experiments, the feedback modality, mapping of environment to feedback patterns, important information from the environment, effect of the feedback, and amount of information were tested and refined. Ultimately, the amount of information was limited to blind spot and large speed difference warnings (i.e., collision detection) to ensure better and quicker perception and interpretation of the feedback.

The vibrating feedback was considered less intuitive in terms of hazard direction than shape change, but it did trigger a high level of attention for immediate hazards making it valuable feedback, provided it receives some fine-tuning. This feedback state will likely be more effective after a short learning period and when preceded by shape change indication a clearer direction. The subtle informing feedback, representing the blind spot, was intuitive and very much appreciated by motorcyclists.

Limitations and Future work

Technical implementation

A clear limitation at this moment is the technical implementation to achieve the shape change in motorcycle grips. It is likely that, when developing a higher fidelity prototype, a custom handlebar will be required for installing the grips on an actual motorcycle. This would make the grips less accessible, as they will probably be built-in.

Parameter tuning

The current feedback consists of vibration and shape change that has a couple of parameters that require fine tuning, especially since these are refinements that have not been tested yet. They include vibration frequency and amplitude, feedback activation reach, and shape change expansion and speed, as well as their relations. A set of experiments should test different patterns of these parameters to find an optimum in reaction time and situational awareness.

Long-term effect

A long-term study is needed to find the effect of the feedback after a learning period and should validate that the correct responses are triggered by the feedback. For highly complex systems, such as nuclear power plants, safety systems could add complexity that ultimately leads to a "normal accident" [30]. Despite being specific to complex systems, driving is a complex task [18,22], posing a similar risk for adding haptic feedback to the task of driving that cannot be neglected.

Handleability

During testing and demonstrating the design, some concerns were expressed about the impact on handleability of the motorcycle when the grips change shape. A solution could be to limit the expansion, but that would introduce problems for perceiving the feedback, especially while wearing thick (winter) gloves. A better solution would be to use force rather than shape change, so users can push the shape change back to keep a better grip on the handlebar. The underlying assumption here is that the information is in fact conveyed in the exerted force, not shape of the grip, which requires testing.

Future steps

Finally, since the design was appreciated so much by many motorcyclists, the design will be submitted for the James Dyson Award, opening up the possibility for more expert feedback, media attention, and funding for further development. The government and police are potential clients that could benefit from this design, and provide more certainty regarding selling the product, which can be an interesting business proposal for BMW Motorrad (the manufacturer of police bikes in the Netherlands).

Conclusion

The vulnerability combined with poor visibility of motorcyclists is a serious problem that is unlikely to be solved by designing for other road users. The limited innovation of ITSs for motorcyclists show a promising opportunity to design a system to help motorcyclists navigate safer in traffic. Strikingly, a large amount of information is communicated through visual and auditory signals, causing an overload of these types of information [14,32]. Through multiple (sub)iterations and tests, a design for handlebar grips providing haptic shape changing feedback emerged, that work in parallel with vision, instead of replacing it.

The process started by exploring the problem and solution domain using questionnaires, which highlighted the visibility problem and showed disapproval of unnecessary "gadgets" that could cause distraction or impact the hobby aspect of motorcycling. The design of InForm focuses on providing valuable information in a way that naturally maps to the environment and with great care not to cause unnecessary distraction, both validated through multiple user tests.

InForm indirectly addresses the visibility issue by providing meaningful situational information through tactile feedback, on which the user can act accordingly. Thereby, it improves situational awareness and reaction time. Ultimately, this contributes to a safer ride [14,21], with fewer traffic accidents resulting from poor visibility, and without jeopardizing the hobby aspects of motorcycling.

In terms of concept and experience design, InForm has proven its value. However, to be implemented as a final product, there are some essential areas that still require testing and refinement, including testing the long-term effect and automatic response to the grips over type, developing a sturdy, yet small, mechanism that can be implemented as actual grips on a motorcycle, fine-tuning the haptic parameters to maximize the effect on reaction time and perception of hazards, and lastly, ensuring the perception of haptic information through thick gloves and rough road conditions, without impacting the handleability negatively. These will be tackled in further development with the help and/or financing of additional parties.

Acknowledgements

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Appendix

The appendices include files not suitable for a PDF format. Therefore, they are included as a separate .zip file. Their contents are described below.

Appendix A – Experiment materials iteration 2.1

The appendix includes the protocol, Processing code, animations and CSV data that was used during the first experiment of this report, i.e., iteration 2.1.

Appendix B - Results of thematic analysis iteration 2.1

This appendix shows the resulting themes from coding the raw test results of iteration 2.1. The numbers underneath the themes (yellow cards) are the number of different participants that were in accordance with the theme.

Appendix C – Experiment materials iteration 2.2

This appendix includes the experiment materials including the protocol, sounds, worksheets, Unity code and other relevant documentation for the experiment.

Appendix D - Results of thematic analysis iteration 2.2

This appendix shows the resulting themes from coding the raw test results of iteration 2.2