Reliv

An interaction design to help relieve people's discomfort in AVs

Future mobility M11 Design Project

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Introduction

The transportation system is in a stage of rapid development. As of December 2024, autonomous driving technology has made significant progress worldwide (Atakishiyev et al., 2024). For example, Tesla plans to launch its Full Self-Driving (FSD) system in China and Europe in the first quarter of 2025, currently awaiting regulatory approval (Bao, 2022). In China, several cities are actively expanding autonomous driving test areas, such as Hangzhou and Shenzhen. However, for the time being, due to safety and regulatory developments, it is still a long way from autonomous vehicles (hereafter referred to as AVs) completely replacing manually driven vehicles (hereafter referred to as MDVs). Depending on the use of existing AV technology, it is expected that AVs will account for 50% of all traffic by 2040 (Litman, 2017). Therefore, in current estimates, AVs and MDVs will coexist in the transportation system for a long time, which is referred to as mixed traffic. As a result, it will be necessary to address various issues in this area, especially regarding human experience.

There are some related studies in this field. Mahdinia et al. (2021) studied the safety impact of AV following MDV behavior on MDV driver behavior in mixed traffic. Ma and Zhang (2024) explored the impact of driving style on the perception and decision making of human drivers in mixed traffic. It can be found that there are only a few studies on AV passengers.

The development of autonomous driving technology is completely changing the design of vehicle interiors, shifting the focus from traditional driving tasks to non-driving activities (Yang et al., 2019). People’s trust in AVs is the root cause (Hamburger et al., 2022). This shift has given rise to new interior design ideas that prioritize passenger comfort, relaxation, and interactivity (Hirz et al., 2021). Relaxation and comfort have become common design pursuits. Therefore, the design will explore ways to alleviate discomfort from the perspective of passengers without a driver’s license in AVs. Consequently, this design aims to explore the emotional experience of passengers in AV in mixed traffic situations.

Related works

Shape and color associations

Human brains naturally make systematic associations between features from different sensory modalities, such as sound and light, also known as cross modal correspondence (CC) (Spence, 2011). Research shows that CCs occur between tangible 3D objects, visual colors, and emotions, leading to various emotional responses based on different shapes. Rounder and less complex shapes trigger more pleasantness, while angular and more complex shapes trigger more unpleasantness (Lin et al., 2021). According to Steer et al.’s study (2024), stiffness plays an additional role, where a more rigid stiffness of a shape is experienced as having more control.

The way colors are associated with shapes differs for each person, as their strategy is influenced by personal preferences and prior experiences (positive or negative). However, a correlation can be found in the association of softer shapes with lighter hues, such as greens and blues, and more rigid shapes with darker hues, like red. According to Lubos’s study (2008), the color blue has the highest effect on stress reduction in the context of light therapy. Together with the pink color, they have a calming and soothing effect on people. Therefore, combining a relieving color (blue) with a rounder and softer shape harnesses the association most people make with tangible objects.

Handle

Cars are often equipped with several contact points to rest the participants' hands. Often in the shape of handles located on the door, above the door or on the dashboard or at the middle console. Car door handles are crucial components for vehicle access and passenger safety (Kumar, 2024). These handles come in a big variety of shapes, sizes and materials.

Current handles are usually designed to be simple to manufacture and offer easy access to grab. Benchmarking different car interior designs of the future created a common vision on the design landscape, resulting in a mood board (Appendix A) showing innovative interiors and various handle applications. Additionally, research is conducted to explore a variety of handle shapes in different applications, such as rock-climbing handles. These handles seem most relevant as they offered secure grab and came in a wide variety of shapes and sizes. Initiating a study into a most suited shape for the project’s design challenge.

Shape study

The shape study explored the ergonomic feel in new handle designs, using a soft deformable plastic (TPU 85A) in a 3D printer. The goal was to find a shape that felt comfortable to grab, while being flexible to absorb the force and for them to potentially feel a core material. With a focus on shape and the size of the handle, various CAD models were made in SolidWorks and

3D printed to evaluate through experiencing within the team. The figure below shows the different stages during the study towards a final design.

Figure 1: The 3 stages during the study towards a final design

Multimodal design

Multimodal design is part of the focus of our design. After research and selection, the multimodal part of our design focuses on touch and sight.

Sound

According to research, music and white noise can be very helpful for relaxation, but when the scene is an emergency brake, relaxing sounds can affect the passenger's judgment of external events (Gonzalez et al., 2003). Moreover, passengers have the possibility to choose music to play while they are in the car, and suddenly interrupting the music they have chosen is likely to cause bad emotions. Therefore, the sound option is deemed illogical for this design project.

Touch

Touch is another important part of the design, and it serves the main function of relaxing the mood. Touching soft objects is a relaxing and enjoyable process (Davis, 1999). Emotional touch has been proven to be an effective experience to relax, which is a conclusion that has been widely used in psychotherapy (Sefidgar et al., 2015). Therefore, the design adopts a touch approach.

Vibrations

Vibration-based haptic feedback is an emerging area of exploration in the automotive environment. A study by Gaffary and Lécuyer (2018) examined the application of vibration on devices as dashboards, steering wheels, seats, etc. They found that haptic feedback appears to be an effective way to reduce visual workload and convey information. Some studies have shown that while vibration feedback is generally pleasant, it has limited effectiveness in conveying complex or subtle information (Väänänen-Vainio-Mattila et al., 2014). In situations where users need to understand information quickly (for example, during emergency braking), vibration may not provide clear or easy-to-understand prompts. When visual, auditory, and haptic feedback are present at the same time, users must process haptic feedback and primary tasks at the same time, which reduces overall performance and user safety. At present, vibration-based haptic feedback has not been fully explored, but vibration may be a possible way to relieve discomfort and be applied in the in-vehicle environment in future.

Scenario

This project focuses on the emotions that passengers experience in a future scenario where SAE level 4-5 automated vehicles (AVs) are becoming the norm, but manually driven vehicles still exist. Level 4-5 automated vehicles can operate fully autonomously in specific to all conditions and handle all driving tasks without requiring a passenger to take control of the vehicle (SAE Levels Of Driving AutomationTM Refined For Clarity And International Audience, z.d.). The mixed traffic scenario, in which fully automated and manually driven vehicles share the road, is the foundation for this project and based on the research of PhD. Gao Roulin, expert at the Future Mobility squad. The target group consists of adults without driver's licenses who commute daily between their homes and workplaces using fully automated vehicles. Since they do not need to control the vehicle, passengers are expected to disengage from their surroundings and use their commuting time for other activities, much like what is commonly observed in public transport (Frei et al., 2015). However, unexpected events cannot be ruled out in a mixed traffic situation causing abrupt movements. Haoyu Dong et al. study on Automated surprise states “These abrupt movements elicited immediate reactions of fear, anxiety, stress, confusion, and caution. Such AS [automated surprize] was not confined to highspeed scenarios but also occurred during slow-speed city driving or smooth deceleration after a prolonged period of steady driving.” (Dong et al., 2024). Therefore, the design challenge is: How can we alleviate discomfort for passengers in automated vehicles during abrupt braking events in mixed traffic situations?

Figure 2: Storyboard of scenario

Design process

For the design project, the Reflective Transformative Design Process (RTDP) design methodology was used (Hummels & Frens, 2009). The process cycled between five key phases of Envisioning, Integrating, Making, Verificating, Thinking and Reflecting. Through continuous reflection, understanding was deepened, and the design was continuously optimized and refined. The figure on the right introduces the design and iteration process.

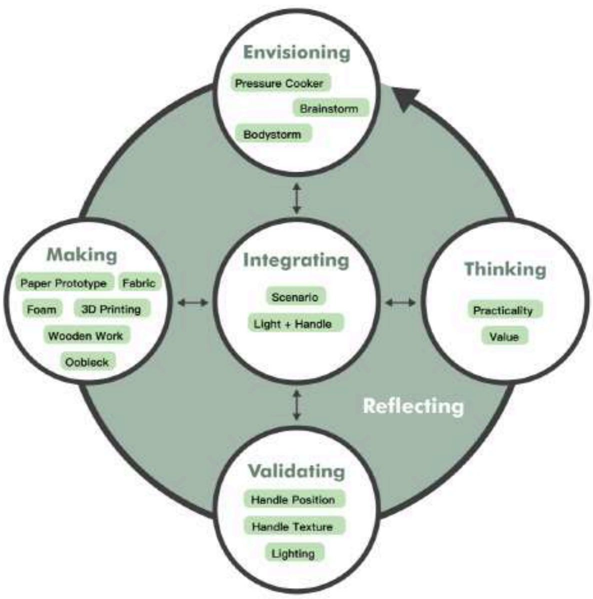

Figure 3: Design process

Envisioning

In the Envisioning phase, the direction was gradually narrowed down through storytelling, and the design scenario was defined as alleviating the discomfort of passengers unfamiliar with traffic rules in a mixed traffic scenario of a two-seat car with level 5 autonomous driving in the future. By enriching the specific scenarios, the design direction could be grasped more accurately. Conceptualizing and designing the passenger experience in a self-driving car, with a focus on emotional and physical reactions during emergency braking, helped in better iterating the design and guiding subsequent decisions. During this phase, different concepts and design directions aimed at alleviating discomfort during emergency braking were explored. Brainstorming was used to explore as many possibilities as possible, such as the use of tactile feedback, auditory feedback, visual cues, etc., to provide more design possibilities through conceptualization.

Integrating

After envisioning, integrating will combine and narrow our ideas and generate new directions. This is a beneficial way to iterate. Ideas and insights gained from iterations and reflections were integrated to form a coherent design concept that further enriched the "story." Ideas and concepts were collected and considered to explore more possibilities. This phase involved integrating multiple design elements into a unified whole, making the design more comprehensive.

Making

The integrated concepts were transformed into concrete prototypes. Different prototypes were built and tested to explore how the design would perform in real environments, using technologies as 3D printing, Arduino, and using materials as fabric, wood, foam board, lighting to explore how the design would perform in a real environment. By creating and experiencing the prototypes, the potential to reduce passenger discomfort during emergency braking was evaluated. The design was continuously adapted and optimized through the actual production and experience of the prototypes.

Validating

In the Validating phase, user testing and feedback collection through interviews were the focus to validate the effectiveness of the design. Target users were invited to conduct user testing in a real car while driving to assess whether the design achieved its intended goals. User feedback was used to identify strengths and weaknesses in the design, and further adjustments and optimizations were made accordingly.

Thinking

Thinking is a reflective process in which the progress of the design was reviewed and examined, and the value of the design was considered. This phase involved deep consideration of the passenger's feelings in AVs in a mixed traffic scenario and how the design affects the overall user experience. They provided valuable ideas and direction for future designs, particularly for reducing passenger discomfort in self-driving cars. Thinking can focus more on solving possible problems within the scenario and improve the design from a more macro perspective to provide value for future designs.

Reflecting

Reflection is an ongoing and central part of the design process. At each stage, the design process was reviewed to assess whether it was moving toward its intended goals and to identify new possibilities. Reflection helped determine whether adjustments to direction or improvements to certain design details were needed. By reflecting on user feedback, prototype test results, and theoretical analysis, more informed decisions were made, and the design was continuously optimized and improved throughout the cycle.

Hugging concept Iteration 1

Situation defining

The first iteration started off with a deep dive in a specific traffic situation, in this situation, traffic merged onto the road where simultaneously traffic exited. This creates a complicated scenario for automated cars where passengers can feel overwhelmed but also experiencing anxiety due to automation surprise (AS) (Dong et al., 2024).
To get better insight into the feelings passengers of the automated car might feel a small study was done by sketching out the road situation with 3 different traffic situations. In figure 4 the test situations are shown. In a quick walk-by session through the faculty, the participants were asked to place themselves in the hypothetical situation starting a chat on their feelings throughout the different scenarios. People expressed reoccurring feelings of feeling unsafe, unpleasant, or scared. This showed potential for a design in relieving these uncomfortable feelings. A follow up brainstorming resulted in 3 main directions: user input, providing feedback to the user and exploring multimodal interactions.

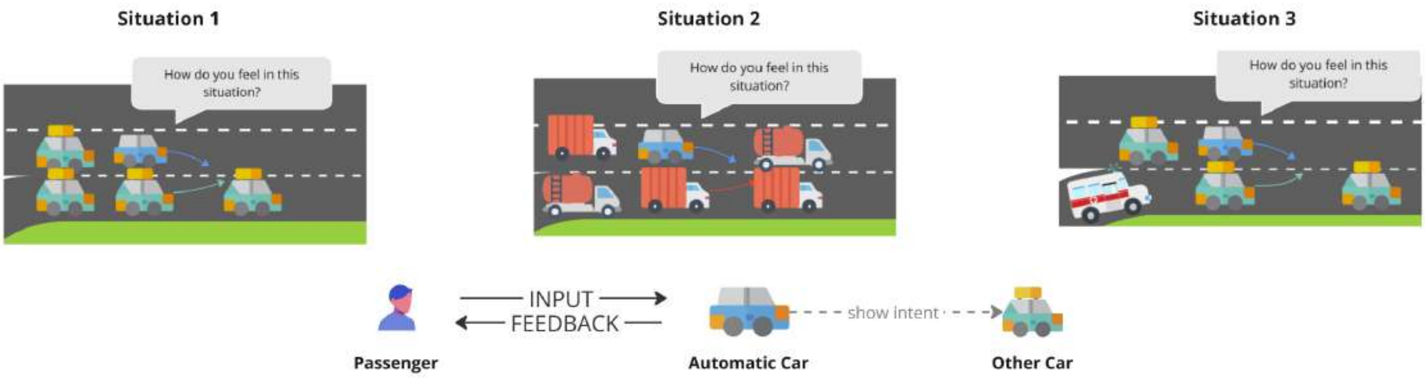

Figure 4: The 3 traffic situations used for the discussions and an overview of the 3 main directions

Situation defining

Change in situation

Looking at the situation of the project, we felt that it lacked some key features. The situation was exceedingly rare, the likelihood of the passenger noticing it was low, and design options were limited. Therefore, using the video database of situations created by PhD. Gao Roulin, new traffic conditions were explored. The most interesting videos had sudden and abrupt braking, as the expectation was that the passengers would not pay attention and therefore be put in a shocking situation (Frei & Frei, 2015). The assumption was made that this would create discomfort for the passengers of the automated car.

Pressure cooker

To swiftly move from this renewed situation to a concept, a 1-hour pressure cooker session was held containing 5 different techniques: brainstorming, bodystorming, mood boarding, sketching, and quick and dirty prototyping.

The brainstorming step resulted in a mind map with feelings that might occur in an unforeseen sudden braking moment. To verify these feelings the second step was a body storm, experiencing a simulated event of a sudden brake in a wooden car. This revealed the feeling of discomfort even in a simulated body experience. The 3rd step was a mood boarding session using Pinterest to gather a coherent design vision for the time span of the project. Followed by sketching as 4th step, exploring feasible concepts within the time frame that could help alleviate the discomfort felt during an abrupt braking event. Lastly, a joint venture of quick and dirty prototyping brought the sketches to life and created discussion probes to reflect and make a decision on the further design direction.

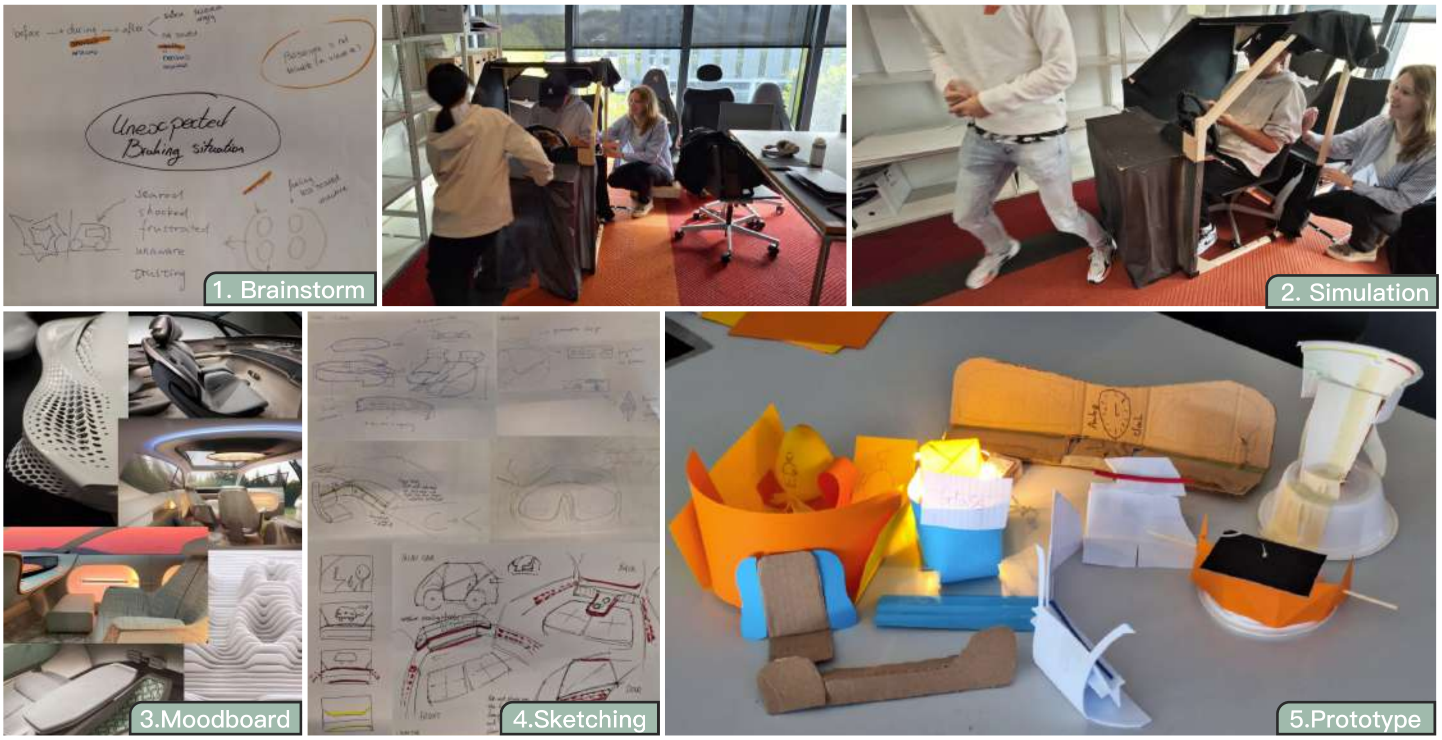

Figure 5: Different stages of the pressure cooker, the images of the moodboard are adapted from Pinterest

Finalizing the 1st iteration

The direction of the 1st concept contains light and a place to grab. The LEDs could create a display that would simulate a hug around the passenger from the car seat to the dashboard in front. In the dashboard, spherical soft objects would appear for the passenger to grab, like a stress ball. The stress ball's function was to facilitate somewhere to hold on to as the body storm revealed the absence of something to grab. The hugging LEDs were a result of the sketching and quick and dirty prototyping and an iteration on the hugging chair as the chair could lead to a feeling of entrapment. Therefore, the preference is using lights as they would serve the same purpose without enclosing the user, while directing the passengers' view towards the front of the car where the ball would appear.

Figure 6: Prototypes of first iteration

Evaluating and verifying

The pressure cooker and the first concept relied on many assumptions about the feelings the passengers would experience from an abrupt braking event. Additionally, it was unclear if the hugging element of the LEDs would translate as intended. The midterm demonstration day was chosen to verify and test the concept.

The main feedback gained was about the shape of the ball and the suddenness of the lights appearing. The ball was not easy to grab, and it did not give the same relief as other measures in the car like existing handles or seatbelts. The timing of the lights resulted in a warning feeling instead of the hugging comforting feeling. As a result, the idea for the next iteration was to create a more 'grabbable' shape and reprogram the LEDs to be more comforting.

Handle concept Iteration 2

Concept development

The second iteration explored a more suitable shape (based on shape study), material, and position for holding. The design object was placed on the middle console, because this was close to the passenger and offered for feasible manufacturing. During the exploration of materials, a non-Newtonian fluid apposed promising experiences that aligned well with the goal of the handle. It adapts to the force given by the passenger, being stiff at high pressure and dynamic when pressure is released. Besides the concept, the world in which it would be based also changed. A choice was made for a two-seater, compact, AV without a steering wheel. This was done based on discussions on the future of mobility and the urbanizing landscape.

Test and questionnaire

To evaluate the renewed concept a user test was set up. The research had a few main goals, identifying the hand placement locations, reflecting on feelings during an abrupt braking event, and evaluating the concepts functions.

Test environment

The test environment was a parking lot on the TU/e campus, and the car was driven at a slow speed (about 15 km/h). A two-seater car was selected, and a black cloth was placed between the two seats. The test subject was in the passenger seat and did not see the control systems, thus simulating the situation of a passenger in an autonomous driving scenario. A camera was placed inside the interior to monitor the participants' behavior during the braking event.

Figure 7: Test location and car

Figure 8: Test setting

Test objects

Test object 1 is the location of the design. The design object is placed on the center console, but the participant is allowed to touch any part of the car to feel more comfortable in an abrupt stop. This explores where the design is more suitable for contact.

Test object 2 is the material of the core. A non-Newtonian fluid was chosen as the core, but another material (soft silicone) was also provided as a replacement. The participants would feel both materials to compare and evaluate what they thought was the most relaxing in the test environment.

Test object 3 is the lighting. A light with a blue-violet gradient and blinking light was chosen to test whether it can attract the attention of the testers and bring a sense of relaxation and guide the participants' attention to the handle.

Figure 9: Materials used during test including the in car test setup

Test and questionnaire results

After the test, a questionnaire was used to investigate the participants' psychological feelings in more detail. The participants generally looked for something to touch, and half of them chose their legs as the object to touch, while the other half chose to touch the interior of the car. Among the locations in the car, the ratio of touching the front desk to the door handle was about 1:1. The participants generally agreed more with the experience brought by non-Newtonian fluids, because soft silicone is too soft and easy to deform. The participants also saw the lighting but were not sure what role the lighting played.

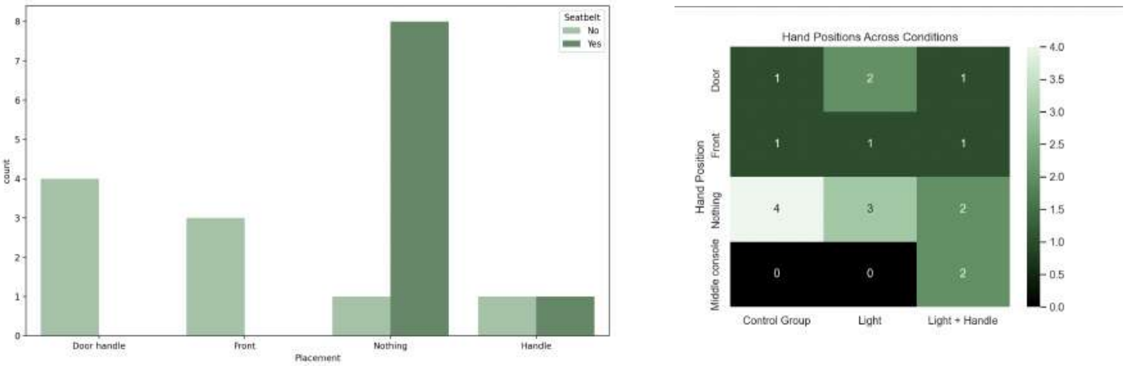

Figure 10: Data visualisation of hand placement data from the test generated using Python and the Seaborn library (Appendix B)

Reflection

The position of the design object on the center console is obviously not suitable, as it does not match the position of the human subconscious response to instinctively grab in an emergency brake. In the next design, the front desk and door handles, which are touched by more people, will be explored. The relaxation experience of non-Newtonian fluid has reached a consensus, but it was found in the test that this material will harden when it gets cold, and its sustainability is average. The attention-grabbing effect of the light has achieved its purpose. The participants were not sure about the role of the light, which may be related to the problem of the position of the design object.

Portable grip extension Iteration 3

Refining concept

As the analysis of the hand placements during the test concluded various positions the concept is refined to a portable grip extension. This allows for personalization in the preferred placement of the extension and in the relaxation experience. The lighting remains unchanged but is simplified to a purer, slower blue twinkling effect, which is expected to not be interpreted as immdiate

Figure 11: The rendering of the envisioned car interior

danger. Regarding the material, the actual car interior can direct heat to the part of the design object, so no heating device is added to the prototype to maintain the softness of the non-Newtonian fluid.

Latest prototype

The latest prototype, called Reliv, it's exterior is a soft fabric material in a light grey color that allows the light to go through. Its core is filled with non-Newtonian fluid which is wrapped with a LED strip for the light animation that notifies the passenger. The entire prototype is portable, allowing it to lay flat on the dashboard, wrapped around the door handle, or being placed around any desired location. In this way, passengers in the AV could experience the alleviating effect of the prototype in a personalized manner. Also, it allows for easy manufacturing while maintaining adaptability so customers with various cars can buy and use it in any car without modificatmodifications..

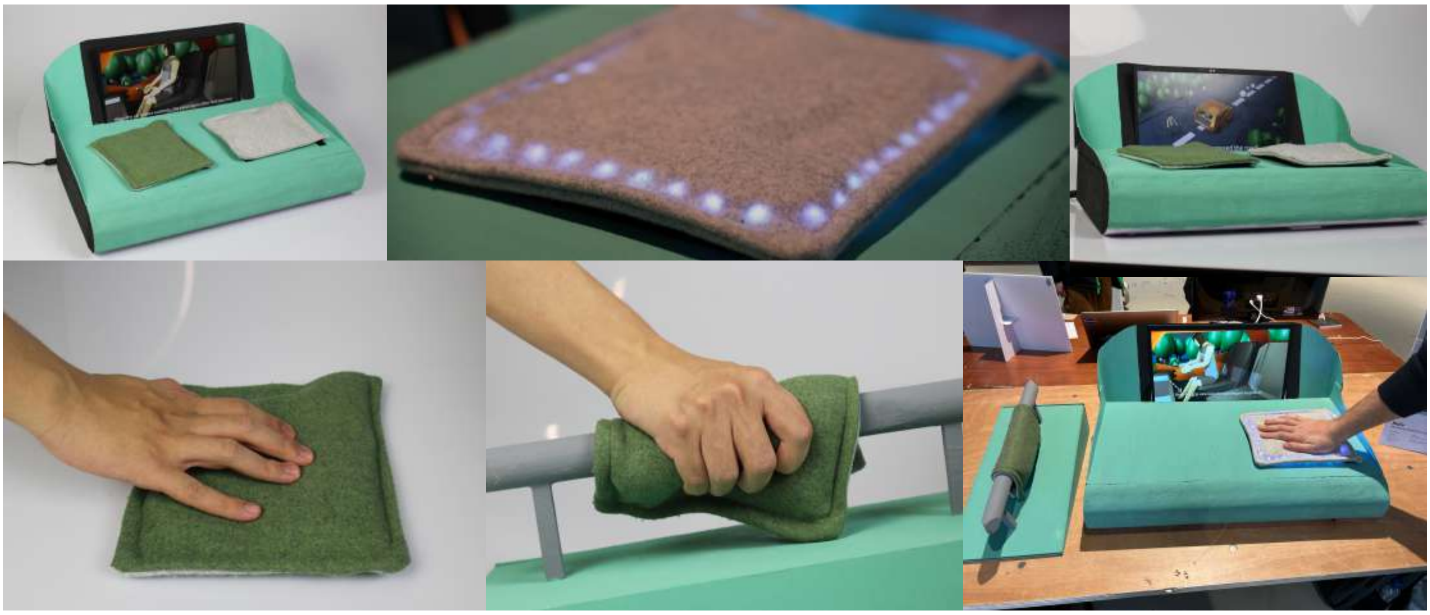

Figure 12: Pictures of latest prototype

Reflection

From the experience on the day of the exhibition, it can be found that this design can indeed bring a sense of relaxation, but there are also some problems. The main problem is still with the material. How to keep the material soft, rather than hardening when cold, will be the direction of subsequent design exploration. Perhaps it can be replaced with other materials that achieve the same effect and do not require heating. Moreover some feedback arose about different traffic situations, in which the design would take on a different role as a fidgeting toy or as an indicator for busy traffic. These options could still be explored.

Figure 13: Demo day presentation

Discussion

Time issues

As a result, of testing our second iteration, a very well-thought-out experiment came with a elaborate ERB-form. To make sure it would pass directly, to not lose too much time, this form was well written. Unfortunately, this also costs a lot of time. Resulting in user testing the second iteration only 3 weeks before the deadline of this report. Consequently, the essence of the third iteration relies on the findings of the user test done on the second iteration and there has not yet been any evaluation to a similar extent for the third iteration.

Shortcomings of the test

The user test was not flawless either and came with some sacrifices. The test was not done in a self-driving car but in a manual driven car (even with a clutch peddler). This already limited the feeling of a futuristic car. Moreover, the car was a diesel car, something we right now can already see is not where the future is heading, also the noise of the engine could have had an impact on the results.
The location of the user test was on an empty parking lot for safety reasons. Unfortunately, the road is rarely empty and as open in a real driving environment.
Some participants were not clearly instructed to wear a seatbelt, this might have had a big influence on their behavior in an abrupt braking moment. An additional part that could have made the test stronger, was the addition of a task during the driving, for example giving them a game to play, to keep their minds distracted from what was about to happen, as we needed to inform the participants that we would do an abrupt brake during the experiment.
Lastly for two of the participants the LED connection broke, resulting in continuous looping of the animation instead of one time during the braking moment.

Far future speculations

As this concept is spaced in the far future, where level 5 autonomous vehicles are roaming the road together with manual driven vehicles the design. This means that it is difficult for participants to imagine such a situation, resulting in difficulties in evaluating the product. It also means that the interior of cars is completely different from todays, creating not a necessity for Reliv to be part of the interior. This also means that Reliv should be looked like a possible solution to alleviating discomfort of passengers, in a very specific scenario. For future products it could be useful to look back at Reliv and take elements like the security and dynamic nature of the product. Or the localization of the blueish LEDs.

Future steps

Evaluate

Unfortunately, the final design has not yet been validated, due to the short time span of the project. Therefore, the next logical step would be to do a similar test as in the second iteration. The added value of a true sudden braking experience is key in the design. Consequently, the setup could be identical, but preferably with a truly automated vehicle. A more realistic approach would be an electric two-seater car, to minimize noise and clutch noise in braking and accelerating. The objective of this test would be to see if the product achieves its purpose of alleviating discomfort, if the LEDs would direct the user to the product and how the user would interact with the product.

Hand placement

In addition, further research into hand placement during abrupt braking could offer more insight into possibilities for placing the design or changing the design to be more appropriate shaped. Moreover, it could help answer the question of whether the product should be built-in the car's interior or a separate moveable product. It both has its pros and cons, but hand placement in the car would be the most important, as when users prefer a multiplicity of locations a moveable product is more sensible. In contrast when only one designated location is preferred a built-in option could be more logical.

Core material

One major weakness of the current design is the non-Newtonian fluid. The material aspects are one of the main selling points of the design. It becomes stiff under pressure and releases it when the pressure is let go. This enhances the feeling of relief. The issue with the fluid is its contents, it is made from corn starch and water. Which makes it organic and prone to going bad after several days.

Air pressured balloon-like structures like those used in soft robotics might give a solution to this issue. More options should be explored in the future to create the same with tactile feeling.

Conclusion

The proposed design project concept aimed to address a new way to alleviate passenger discomfort during sudden braking events in AVs in mixed traffic situations. Through an iterative design process and user feedback, the project developed a modular, tactile, and visually interactive grip extension that assists passengers in AVs. It provides advanced notification of a sudden event using light and serves as a secure grip that gives a tactile relief response through the non-Newtonian fluid material in its core.

The adaptability of the grip extension allows passengers to personalize the placement to their preference, addressing the variety of hand placements during abrupt braking. Testing and feedback emphasized the need for a secure grip during these events but also revealed the need for further research on hand placements to improve the effectiveness of the extension. Additionally, it revealed that the core material non-Newtonian fluid as a gripping material can effectively alleviate the passengers' discomfort in emergency situations, but it also revealed that it has challenges with the durability and temperature sensitivity, requiring a further study of alternatives.

Despite the limitations encountered during the design project, such as the focus on a future situation and the lack of a level 5 AV for testing, the project contributes to the potential of integrating tactile experiences and visual interactions to improve the passenger experience in AVs. Future work should focus on further research into passenger hand placements, alternative materials, and their coherent effect. Moreover, validation in a more realistic setting of SAE level 5 AVs will be critical for future iterations.

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Appendices

Appendix A

The mood board that served as inspiration on the handle shape

Figure 14: A mood board visualizing a benchmark for inspiration sourced from Pinterest, Etsy and Google Images.

Appendix B

The code of the data visualisations written in Python using the Seaborn Library

```
data = {
    "Participant": ["P1", "P1", "P1", "P2", "P2", "P2", "P3", "P3", "P3",
                    "P4", "P4", "P4", "P5", "P5", "P5", "P6", "P6", "P6"],
    "Condition": ["Control Group", "Light", "Light + Handle",
                  "Control Group", "Light", "Light + Handle",
                  "Control Group", "Light", "Light + Handle",
                  "Control Group", "Light", "Light + Handle",
                  "Control Group", "Light", "Light + Handle",
                  "Control Group", "Light", "Light + Handle"],
    "Placement": ["Door handle", "Door handle", "Door handle",
                 "Front", "Front", "Front",
                 "Nothing", "Nothing", "Nothing",
                 "Nothing", "Door handle", "Handle",
                 "Nothing", "Nothing", "Handle",
                 "Nothing", "Nothing", "Nothing"],
    "Seatbelt": ["No", "No", "No", "No", "No", "No",
                 "Yes", "Yes", "Yes", "No", "No", "No",
                 "Yes", "Yes", "Yes", "Yes", "Yes", "Yes"]
}

custom_colors = {"Yes": "#559261", "No": "#99CAA3"}

plt.figure(figsize=(10, 6))
sns.countplot(
    data=data,
    x="Placement",
    hue="Seatbelt",
    palette=custom_colors    # another colour palette: viridis
)

plt.tight_layout()
plt.show()
```

Figure 15: Python code of the heatmap visualisation

```
data = {
    "Participant": ["P1", "P1", "P1", "P2", "P2", "P2", "P3", "P3", "P3",
                    "P4", "P4", "P4", "P5", "P5", "P5", "P6", "P6", "P6"],
    "Condition": ["Control Group", "Light", "Light + Handle",
                  "Control Group", "Light", "Light + Handle",
                  "Control Group", "Light", "Light + Handle",
                  "Control Group", "Light", "Light + Handle",
                  "Control Group", "Light", "Light + Handle",
                  "Control Group", "Light", "Light + Handle"],
    "Placement": ["Door handle", "Door handle", "Door handle",
                 "Front", "Front", "Front",
                 "Nothing", "Nothing", "Nothing",
                 "Nothing", "Door handle", "Handle",
                 "Nothing", "Nothing", "Handle",
                 "Nothing", "Nothing", "Nothing"],
    "Seatbelt": ["No", "No", "No", "No", "No", "No",
                 "Yes", "Yes", "Yes", "No", "No", "No",
                 "Yes", "Yes", "Yes", "Yes", "Yes", "Yes"]
}

custom_colors = {"Yes": "#559261", "No": "#99CAA3"}

plt.figure(figsize=(10, 6))
sns.countplot(
    data=data,
    x="Placement",
    hue="Seatbelt",
    palette=custom_colors    # another colour palette: viridis
)

plt.tight_layout()
plt.show()
```

Figure 16: Python code of the bar chart visualisation

Appendix C

The ERB, conformation email, and consent form that are used for the test (see next page).

Ethical Review Form

2 Breakdown of test including questions

Main goal of Study: To know how passengers of AV respond in case of a sudden brake, and the effect of our prototype in this type of situation.

Breakdown

To investigate passenger discomfort during sudden braking in automated vehicles (AVs), participants will be seated in the passenger seat of a vehicle modified to simulate an AV experience. Visual barriers will be used to create the illusion that t he vehicle is driving autonomously. The vehicle will travel at a steady speed of approximately 15 km/h before executing an unexpected braking maneuver. A camera will record their body language and reflexes to determine the location of the prototype. Each participant will wear a smartwatch to monitor heart rate changes during the process. The data will be destroyed after six months. Afterwards, a short semi-structured interview will take place to get a better understanding of their feelings during the test and the effect of the prototype

Introduction

The introduction will contain the following steps:

1. Explanation of the test, that sudden breaks will happen, that this will be done on the parking lot (current location) at a maximum speed of 15 km/h, that they will wear a smart watch for heart rate monitoring and that their body will be recorded in the car.
2. Signing informed consent
3. Prepare the participant by putting on the smart watch and (if necessary) install the prototype in the car

Test in car

Each participant will experience three braking scenarios to assess discomfort levels across different conditions:

- Control Condition: Braking without any additional prototype components.
- LED Prototype Condition: Braking with an LED signal, designed to prepare or alert the participant before braking.
- LED + Physical Distress Handle Condition: Braking with both an LED signal and a physical "distress handle" designed to provide tactile feedback and a sense of control.

Semi-structured Interview questions (examples)

1. Below are example questions for the interview, which will be asked outside of the car after each condition.
2. What is your overall feeling through the emergency braking? （subjective）
3. What was the level of comfort/discomfort you were experiencing? (comfortable - discomfortable)
4. How did you experience the ability to grab something during the sudden break?

Reflecting questions (after interviews)

1. Imagine you were driving at a higher speed; would this influence your answers? And if so, how?
2. If you would compare a sudden brake for a car to a pedestrian, would you respond differently? And if so, how?
3. Do you have any other remarks/thoughts/questions you would like to share?

To:
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Date	Reference
November 11, 2024	ERB2024ID469

Ethical review research proposal

Dear,

It is a pleasure to inform you that the Ethical Review Board (ERB) has discussed and approves your application.
Furthermore, the Board wants to draw your attention to the terms and conditions in the appendix.

Success with your research!

Sincerely,

Dr. D. Lakens
Chair Ethical Review Board TU/e

Enclosures
1

The ERB retains the right to revise its decision regarding the implementation and the WMO[1]/WMH[2] status of any research study in response to changing regulations, research activities, or other unforeseen circumstances that are relevant to reviewing any such study. The ERB shall notify the principal researcher of its revised decision and of the reasons for having revised its decision.

[1]WMO: Law on Medical Scientific Research involving Human Beings (in Dutch: Wet medisch-wetenschappelijk onderzoek met mensen)

[2]WMH: Medical Device Directive (in Dutch: Wet op de medische hulpmiddelen)

APPENDIX 1

Terms and conditions

Amendments
When considerable amendments are made to the design of the study or educational activity, or when the time period between ERB approval and start of the study is longer than one year, please consult the ERB.

Privacy and research data management
The ERB would like to point out that collecting, handling and storing personal information is subject to the General Data Protection Regulation. Please visit TU/e intranet for the latest information and regulations on
www.tue.nl/rdm