A Study on Commuting Therapy

Designing a Human-Vehicle Interaction System to Enhance the Commuting Experience with Emotion-based Multisensory Strategies

Master's Thesis in Industrial Design Engineering

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Abstract

Commuting is often perceived as mundane and time-consuming. However, commute also offers an opportune space and time for design interventions that can enhance well-being during the daily commute.

This thesis project explores the design opportunities to enhance the leisure experience during commuting, with a focus on Jordan's Four Product Pleasures. This project reimagines commute as a transition period aimed at improving human well-being, transforming it into a more pleasurable experience. As a result, this project introduces an affective human-vehicle interaction system within the smart cabin, employing multisensory emotion regulation strategies, including vision, aroma, music, and haptics. Specifically, this project details the design of a multisensory experience tailored to driver emotional states during commutes. The proposed design was evaluated through a VR car simulator in a qualitative user study, which revealed user preferences for multisensory experiences.

Keywords: Commute, Driver's Emotional States, Emotion regulation, Multisensory Experience, Well-being.

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Xiaonan Lu, Gothenburg, August 2024

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

AR	Augmented Reality
AV	Autonomous Vehicles
CAV	Conditional Autonomous Vehicles
EVs	Electric Vehicles
PAD	Pleasure-Arousal-Dominance (Scale)
PrEmos	Product Emotion Measure
RtD	Research through Design
SAD	Seasonal Affective Disorder
UEQ	User Experience Questionnaire
UX	User experience
VR	Virtual Reality

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1 Introduction

Most of the key use cases for individual transportation can be classified as leisure experiences [5] [6], highlighting the growing importance of designing for leisure experiences within vehicles. Current in-car leisure options often include video streaming, karaoke, and on-screen games. However, the fierce competition within the automotive industry emphasizes the necessity for exceeding customer expectations [7]. Consequently, Polestar, as a luxury brand, is actively differentiating itself by offering distinctive leisure experiences that go beyond these conventional offerings.

Everyday, 87% of the workforce in the United States, approximately 127 million people, spend an average of one hour commuting by car [8]. For many, car-based commuting (hereafter referred to as *commuting*) has become a daily routine, requiring a significant amount of time spent in vehicles [9]. Millions of people consider their commuting a daily stressful hassle [10]. However, commuting also provides an opportune time and space for design interventions that can enhance the in-car experience [8] and improve driver health [10].

The development of technologies is a decisive factor in designing the leisure experience for commuting. Autonomous Vehicle (AV) technology promises relief from driving-related stress and may fundamentally change the commuting experience [10], which are anticipated to offer the opportunity to utilize commuting time for various activities, thereby reducing or even eliminating the costs associated with travel [11]. Although much of the research [5] [10] [12] and design [13] [14] in academia is centered on AVs, there are still many technical and organizational issues to be addressed before reaching the fully autonomous driving [12]. Furthermore, several experts expressed their belies that the fully autonomous driving will not arrive in 10 years in the interviews.

In this thesis project, the aim was not only to create an innovative and unique leisure experience during commuting but also to ensure that the design could be implemented in future Polestar vehicles. To balance innovation with feasibility, the autonomous driving level was set between Level 3 and Level 4, where drivers are not required to intervene in driving tasks under specific conditions [12]. This technological context can be called as Conditional Autonomous Vehicle (CAV) [12]. Although the technological setting is not fully advanced, recent advancements in sensor and communication technologies are offering new possibilities for enhancing the in-car leisure experience.

- **Human-Machine Interfaces:** Innovations in interfaces can provide more intuitive and engaging interactions, such as head-up displays, brain-computer interfaces [15], haptic interfaces [16], augmented reality interfaces [17], adaptive voice interfaces [18], smell interfaces [19].

- **Emotion Recognition Technology:** Identifying and responding to the driver's emotional state can personalize the commuting experience [20] [21] [22].

- **Health Monitoring and Management Systems:** These systems can track and improve the driver's well-being during the commute [23].

- **Augmented Reality:** AR can offer immersive experiences that enhance navigation and entertainment [17] [24].

The research was set to start from exploring the general user experience (UX) design opportunities for in-car leisure experiences during commuting. To conduct the research, I formulate the main research question:

R1: How can a mundane commute be transformed into a more pleasurable experience through leisure experience?

Several UX themes were identified in a previous study [25] to enhance the commuting experience, where the car is perceived as *a caretaker* [8] [13] [26] [27], *a space for stimulation* [28] [29] [24] [30], *a space for socialization* [31] [32], *Car as a space for transition* [10] [9] [25] [33]. In addition, numerous proposals have been made to rethink the commute as a period of enhancing human well-being through various leisure activities aligned with the last three UX themes, while the transition aspect remains largely unexplored.

Initially, I was exploring the UX opportunities for both passengers and drivers. However, I found that solo driving is still the number one choice for commuting despite the high costs and stressful traffic congestions [9] [34]. Additionally, I conducted two rounds of ideation workshops. After gathering and screening the concepts based on the previously made criteria from expert interview in Polestar, I decided to focus on driver experience during commuting, which is also align with the driver-centric philosophy of Polestar. Moreover, I found that most commuters use daily commute as a "transition time" between work and home [9] [25]. However, there were few studies that focused on the transition of drivers during commuting between home and work. Thus, I decided to focus on exploring leisure experiences for drivers that help them prepare for the upcoming workday or evening.

I presented the work *Commuting Therapy*, aiming to help drivers prepare for their next stage of the day during commutes. However, instead of helping drivers to be productive or seek socialization, I put the focus on the driver's emotional states during the transition, which is more plausible in the autonomous and technological context, and more suitable for the leisure experience theme of this project. Specifically, *Commuting Therapy* focus on the emotional states of the driver, trying to regulate the driver's emotion to the optimal level, preparing them for the upcoming workday or evening. Many studies stated emotion states, especially anger, have a great impact on driving performance and safety [35][36] [37] [38], emotional well-being has also been a key focus in the design of in-car systems [39] [40] [41] [14]. *Commuting Therapy* is to keep the driver in a desired state of mood by providing different stimulus to regulate drivers' states, contributing to flourish well-being after taking commuting as a transition. Regulative efforts will be taken place when the current driver's mood is not desirable. Regarding the desired emotional state, I found that the medium activation is seen as an optimal level of arousal [3], and positive valence is generally considered as a sign of a good user experience [42] in the driving context, which is also the optimal states for high driving performance.

To enable the emotion-based interaction system within the cabin, it's crucial to thoroughly research how the car detects the driver's emotions and how the system can influence them. Therefore, two subsidiary research questions are formulated as follows:

R2: How can an in-car system accurately detect driver emotions?

R3: How can driver emotions be regulated to achieve a desired emotional state through different strategies?

As a result, I proposed the *Commuting Therapy* concept, an emotion-based multisensory design, intended to help drivers achieve the desired emotional states during commutes and thus prepare them for the next stage of their day. The *Commuting Therapy* utilizes multisensory stimulations to create an adaptive environment that mitigates negative emotions during commutes, aiming to transform the daily commute into a pleasurable experience.

In this thesis project, I presented only two typical modes of the *Commuting Therapy* due to time limitations:

- **Home to Work:** The refreshing mode is designed to reduce drowsiness and keep the driver alert in the morning, particularly during winter when many people experience seasonal affective disorder (SAD).

- **Work to Home:** The relaxing mode is intended to help drivers unwind after a day at work.

In the end of this thesis project, I evaluated the *Commuting Therapy* design through a VR car simulator experience, utilizing the Product Emotion Measure (PrEmo), User Experience Questionnaires (UEQ), and semi-structured interviews. The goal was to understand participants' perceptions of the concept itself, based on which several suggestions for the future development of this concept were made.

In summary, this study addresses the gap in the existing literature by focusing on driver-centric leisure experience design in the context of partially autonomous vehicle. Specifically, it contributes to three key areas: (1) exploring leisure experience design for drivers in CAVs, (2) examining emotion-based multisensory experiences to support transitions between home and work, and (3) integrating multiple affective strategies into a single in-car system to create a comprehensive multisensory experience.

2

Literature review

The preliminary study was aimed to understand the background of leisure experiences and the commuting context to define the scope and direction of the design. Firstly, the concept of leisure experience within the automotive context was defined, establishing the scope of this thesis project. This helped clarify which types of design can be categorized as leisure experiences, thereby shaping the design directions. Furthermore, several UX themes were identified to enhance the commuting experience, where the car is perceived as a space for *transition*, *stimulation*, *socialization*, or as a *caretaker*. In addition, I explore the general background of commute and existing design cases for commute. I found numerous proposals have been made to rethink the commute as a period of enhancing human well-being through various leisure activities aligned with three UX themes, while the transition aspect remains largely unexplored. Furthermore, I observed that emotional well-being is also a key focus in the design of car systems [39] [40] [41] [14]. Regarding target users, I did not define a specific target user group at the outset. However, I discovered that solo driving remains the most common option for commutes despite its high costs and the stress of traffic congestion [9]. Therefore, I decided to focus on improving the driver experience during commuting.

Following the preliminary study, I decided to focus on the design direction of the transition during commuting, specifically focusing on emotional well-being. My goal was to facilitate a positive transition in driver emotional states during their commute, effectively preparing them for the next phase of their day. To achieve this, it was essential to address the second and third research questions, which led me to the main study.

The main study focused on exploring emotion detection and regulation within the automotive context. To gain a deeper understanding of human emotions, I researched various emotion theories and how humans express their emotions, with particular attention to driver emotions in the automotive setting. By investigating different emotion detection technologies and emotion regulation strategies, I was able to determine which approaches are most suitable for this project's conditions. This study provides a comprehensive foundation for understanding how emotional responses can be detected, regulated, and influenced in a vehicle environment through various sensory modalities, including vision, aroma, music, and haptics.

All in all, the preliminary study started with a broad exploration of the leisure experience domain to identify design opportunities within the automotive field, specifically focusing on commuting. Through the preliminary review, I established a research direction centered on emotional well-being, aiming to help users transition their emotional states during commutes. Consequently, the main study focused on researching emotion-based multisensory interactions to enhance leisure experiences during car commutes. This literature review provides a solid foundation for proposing future design solutions.

2.1 Leisure experience

Mansourian [6] categorizes leisure into three primary types. The first type is serious leisure, which involves a committed and focused pursuit of a hobby or volunteer work that requires the acquisition of specialized skills, knowledge, and experience. Examples of serious leisure include activities such as woodworking, car repair, and glass blowing. The second type is casual leisure, characterized by activities that require no formal training and are typically undertaken for relaxation or enjoyment, such as watching television, relaxing, or leisure reading. The third type is project-based leisure, which is more complex and time-bound, involving activities like organizing a wedding, participating in an exhibition, or attending a cultural ceremony. Additionally, Allaby and Shannon [43] offer a similar categorization, dividing leisure into structured and unstructured leisure. Structured leisure is typically voluntary, organized, and scheduled, aligning closely with Mansourian's serious and project-based leisure [6]. In contrast, unstructured leisure aligns with casual leisure, encompassing activities that are enjoyable and spontaneous. Polestar aims to develop leisure experiences that fall into the category of casual leisure, focusing on providing spontaneous and enjoyable activities without the need for formal planning or training.

Given the focus on casual leisure, it is crucial to explore how these leisure experiences manifest within the automotive context and to assess the potential design opportunities. A global survey identified key use cases for autonomous individual transportation, including Sleeping & Relaxing, Working & Being Productive, Eating & Drinking, Entertainment, Beauty & Well-being, and Fitness [5]. Notably, with the advent of full driving autonomy, most of these use cases align with casual or unstructured leisure experiences, aside from working and being productive. This trend manifests the growing importance of designing for leisure within vehicles. Autonomous driving promises to free users from the demands of driving, offering them greater opportunities to engage in leisure activities with enhanced safety. However, to align with Polestar's vision and to contribute meaningfully to the next generation of vehicles over the coming decade, our focus will be on harnessing conditional or high driving autonomy, rather than full autonomy. This project aims to enrich casual leisure experiences during commutes, potentially encompassing activities such as Sleeping & Relaxing, Eating & Drinking, Entertainment, Beauty & Wellbeing, and Fitness.

2.2 Commuting

2.2.1 Current commuting situation

Commuting is defined as the daily travel between home and work-place, which does not include work-related travel, but includes trips to work at variable locations [9]. Commute becomes a daily routine that involves driving at the start and end of each day. However, the time spent traveling long distances to work may be considered unproductive and wasteful. The environment surrounding the car commuter, often referred to as the smart cabin, falls short in offering supplementary activities beyond driving [33].

Despite its high costs and stressful traffic congestions, solo driving is still the number one choice for commuting [9]. The report on commuting patterns and trends [34] shows a steady growth in the last decade in driving alone. Therefore, I concluded that the driver experience is essential to improving the overall commuting experience.

2.2.2 Commuting activities

2.2.2.1 work and home commute

Several commuter studies have shown that work and home commute are two different situations, where time is used for different purposes[33] [10] [9] [25]. Most of the commuters use daily commute as "transition time" between work and home [9] [25]. While driving to work is dominated by doing office work cooperatively, traveling home involves more collaborative leisure activities. The work commute tends to be quiet and monotonous, with activities primarily focused on work-related tasks, such as planning the day and coordinating with colleagues. In contrast, the home commute is more leisure-oriented, often used for planning evening or weekend activities, and commuters tend to seek social interactions during this time. These tendencies suggest that the design focus for the work commute should be on mentally stimulating, work-related activities, while the home commute should prioritize leisure activities.

2.2.2.2 Non-driving activities

A study conducted by Pfleging et al. [44] investigated the user needs for non-driving related activities and entertainment during automated driving. The findings indicate that besides traditional activities (talking to passengers, listening to music), daydreaming, writing text messages, eating and drinking, browsing the Internet, and calling are most wanted for highly automated driving. These insights suggest that for a driver-centric experience, particularly when driving alone, activities such as listening to music and daydreaming are among the most sought-after.

2.2.3 User experience themes for commuting

Several UX themes were identified in a previous study [25] to enhance the commuting experience, where the car is perceived as a space for transition, stimulation, social relatedness, or as a caretaker.

- **Car serves as a caretaker:** The car is designed to ensure users' safety, meet their needs, and provide convenience. For example, there are designs aimed at helping users manage stress [8] and incorporate workout options [13] [26] [27].

- **Car as a space for stimulation:** The car has long symbolized freedom and independence, offering thrilling driving experiences [28] or engaging gaming experiences [29] [24] [30] .

- **Car as a space for socialization:** The car serves as a space where users can connect with people who matter to them [31] [32].

- **Car as a space for transition:** Time spent in the car can be used to prepare for the next stage of the day. Users often handle work tasks during their drive to the office and seek relaxation or social connection during their drive home [10] [9] [25] [33].

2.2.4 Design for Commute

Commutes provide an opportune time and space for interventions that contribute to well-being during the workday [8]. Recently, there have been numerous proposals to rethink the commute and turn it into a time for enhancing human well-being through various activities such as stress management, fitness, socialization, gamification and more.

2.2.4.1 Car as a space for stimulation

1. **Gamification**: One approach to enhancing the commuting experience is through gamification. Brunnberg [35] developed a multi-player game, *Road Ranger*, which allows passengers in different cars to play against each other while stuck in traffic. Similarly, Lakier et al. [29] identified opportunities for "cross-car" multiplayer games played among occupants in nearby vehicles, leveraging advancements in automotive technology such as autonomous driving, full-window heads-up displays, and ad hoc vehicle communication.

   Another example is the work by Sundström et al. [45], who proposed full-body interaction games designed to make proper sitting posture more engaging, particularly for children traveling in cars. What is more, Broy et al. [46], who designed a game where all car occupants participate together, fostering a shared experience during the commute. Similarly, Togwell et al. [24] designed a mixed reality gameplay for passengers through AR headset.

2. **Landmark Interaction**: In addition to games, there are interactive applications that allow passengers to engage with their surroundings based on the car's location. Brunnberg et al. [47] suggested a new type of application that provides information about landscapes based on the vehicle's location, enhancing the passenger's connection with the external environment. Matsumura et al. [48] described an interactive car window system designed to support passengers in engaging with the environment during their journey.

3. **Music improvisation**: Music has always played a crucial role in creating pleasurable driving experiences [49]. Kesson and Karl [33] demonstrated a potential IT service that supports commuters by allowing them to sample music directly from their car, moving beyond the conventional music shop experience. Additionally, Eckoldt and Schulz [50] conceptualized the car as a musical instrument, allowing passengers to drum together, creating a positive and collaborative in-car experience. Further exploring the integration of music in the car environment, Krome et al. [30] explored the alignment of music creation with the progression of traffic conditions in an interactive music listening experience, adding a dynamic layer to the traditional in-car music experience.

2.2.4.2 Car as a space for Socialization

Another important aspect of enhancing the commuting experience is fostering social relatedness. Schroeter et al. [31] investigated the potential of cars as social platforms, designing interactive vehicle applications inspired by social networks and urban informatics. Furthermore, Knobel and Hassenzahal [32] proposed *Clique Trip*, an experience aimed at creating a sense of closeness and relatedness among friends traveling in a "motorcade."

2.2.4.3 Car serves as a care taker

There has also been considerable research on integrating fitness and well-being interventions into the commuting experience. Stephanie et al. [8] designed a haptic-guided slow breathing intervention for drivers, using a portable vibrotactile seat cover to guide the driver's breathing, promoting relaxation during the commute. Krome et al. [13] introduced the concept of *AutoGym*, an in-car fitness program that transforms frustrating traffic situations into a fun exertion game. Deserno and Tomas [26] explored the idea of using vehicles as private spaces to monitor health, offering an alternative to smart wearables or smart clothes. Other studies have also explored guided breathing exercises during commuting, using haptic or acoustic feedback to encourage calmness and reduce stress [27] [51] [52].

Finally, emotional well-being has also been a key focus in the design of in-car systems[39] [40] [41] [14]. Terken et al. [14] presented a concept for an in-car system designed to support unwinding after work, incorporating a mood-sensing steering wheel, an interactive in-car environment, and a tangible input device to help drivers relax after a long day.

2.3 Human emotions

2.3.1 Emotion theories

Emotions are generally defined as human responses characterized by distinctive patterns of conscious and unconscious psychophysiological activities [53]. These responses can vary widely between individuals, as they are shaped by personal cognitive appraisals [54]. This inherent subjectivity highlights the need for real-time detection to accurately understand an individual's emotional state, rather than relying on indirect measures.

Emotions can be classified through either discrete emotion theory, which identifies specific emotional states, or dimensional emotion theory, which represents emotions along continuous dimensions such as arousal and valence [53].

2.3.1.1 Discrete emotion theory

Discrete emotion theory proposes that there are a small number of distinct emotions, each characterized by specific patterns of physiological responses, brain activity, and facial expressions. Major models within this framework include six basic emotions proposed by Ekman [55] and the emotion wheel model proposed by Plutchik [56], which illustrates how these basic emotions can combine to form more complex emotional experiences. Among these two discrete emotion models, the basic emotion model [55] is widely acknowledged, summarising six basic emotions as happiness, sadness, anger, fear, surprise, and disgust. Other emotions were regarded as combinations of these basic emotions.

2.3.1.2 Dimensional emotion theory

Dimensional emotion theory suggests that emotional states can be accurately depicted as combinations of various psychological dimensions, such as valence and arousal. According to Desmet et al. [57], a widely accepted dimensional scale of emotions is the Pleasure-Arousal-Dominance Scale (PAD) developed by Russell and Mehrabian [58]. These dimensional models contain valence and arousal. Valence refers to the degree of pleasure associated with emotions, while arousal refers to the intensity of the experienced emotions. Furthermore, another dimension that exists in PAD model is called dominance, which reflects the control ability of humans on emotions, ranging from submissive to dominant [53].

2.3.2 Human emotion expressions

The emotions of humans can be expressed in forms including behavioral expressions and physiological changes [53]. Emotional expressions in humans are crucial for recognizing and managing emotions, especially in driving contexts. These expressions are multimodal, involving various channels such as the face, speech, body gestures, and physiological changes [41]. As Li et al. [22] explain, emotions can manifest in both behavioral and physiological forms.

2.3.2.1 Behavioral expressions

Behavioral expressions include a variety of observable actions, such as facial expressions, speech patterns, and body movements. For instance, a smile or frown, the tone of voice, and gestures like clenched fists or a relaxed posture all communicate emotional states.

Ekman and Friesen [59] demonstrated that at least six core emotions (anger, fear, disgust, happiness, sadness, and surprise) can be universally recognized across different cultures through facial expressions. The six discrete emotions are universally identifiable and provide clear reference points for understanding human emotional experiences. Additionally, Research by Russell [60] shows that facial expression appears to reliably indicate the valence of a person's emotional state. For example, Duchenne smiles that involve wrinkling of muscles around the eyes are reported to be associated with positive emotional experiences. In contrast, negative emotion inductions are often associated with visible facial behavior in which the eyebrows are raised and brought closer together [61].

What is more? Speech conveys emotional information through both linguistic and acoustic cues, reflecting how words are spoken [62]. The linguistic content of speech carries emotional information that can be directly inferred from the surface features of words, as summarized in emotional word dictionaries [63]. Additional emotional meaning can be understood by considering the broader semantic context, such as discourse information. Beyond linguistic messages, acoustic cues also convey rich information, including age, gender, and hometown. Acoustic expressions are defined by speech prosody (pitch, loudness, rhythm); for example, a happy voice typically has a higher pitch, louder volume, and faster rate, while a sad voice features a lower pitch and slower speech rate.

Acoustic expressions are effective in distinguishing between basic emotions [64]. Each of the six basic emotions—anger, fear, disgust, happiness, sadness, and surprise—correlates with distinct acoustic changes, such as variations in pitch, intensity, duration, and spectral qualities. In addition, acoustic expressions vary along the continuous dimensions of valence and arousal. Research consistently shows a strong relationship between arousal and pitch, with higher arousal associated with higher pitched vocal expressions [65]. However, while pitch is a reliable indicator of arousal, finding acoustic characteristics sensitive to valence is more challenging, as valence often relates more closely to the textual content of the speech rather than its acoustic properties [66].

Lastly, numerous studies have highlighted the crucial role that body language plays in the transmission of emotions [53]. Nonverbal cues such as facial expressions, body postures, gestures, eye movements, touch, and the use of personal space communicate specific information about an individual's emotional state.

Based on the dimensional emotion model, Glowinski et al. [67] found that the trajectory of head and hand movements can distinguish emotion groups in the valence-arousal space. These were divided into four categories: high-positive, high-negative, low-positive, and low-negative. Kosti et al. [68] analyzed emotional expressions by examining features of the body and background, focusing on intensity, arousal, and dominance. Research also extends to discrete emotion models. Gunes and Piccardi [69] showed that simple representations of the upper body can categorize postures into six emotions: anger, disgust, fear, happiness, sadness, and uncertainty. Castellano et al. [70] demonstrated that dynamic body postures could be classified into anger, joy, happiness, or sadness. Saha et al. [21] identified gestures associated with five basic emotions: anger, fear, happiness, sadness, and relaxation, using geometric skeletal features.

2.3.2.2 Physiological expression

At the same time, physiological changes, such as variations in heart rate, skin conductance level or skin temperature, offer internal indicators of our emotions. Although individuals may not always clearly express their emotions through speech, gestures, or facial expressions, changes in their physiological patterns are inevitable and detectable [71]. Each emotion is believed to have a specific and consistent autonomic response pattern. Various physiological responses, such as changes in galvanic skin response, heart rate, blood pressure, finger temperature, and heart rate variability , are associated with different basic emotions [53].

2.3.3 Driver emotions in automotive context

Negative emotions, such as anger and fear, are often sparked by various driving-related factors. The triggers include traffic-related events caused by other drivers [72] [73], environmental conditions [72] [37] and participation in near-accidents [72] [74]. Zepf et al. [73] also noted that frustration often arises from poor interactions with vehicle user interfaces, particularly navigation systems. Other sources of negative feelings include dissatisfaction with one's own driving performance [72] [73], stressful conversations with passengers [74], time pressure [74], and insufficient capabilities of the car [72].

Given that the goal of this emotion-based project is to avoid fostering negative emotions and not to steer users towards them, it is crucial to consider the factors that trigger such feelings. These factors can serve as valuable input for the system in assessing the user's emotional state more accurately. By recognizing the elements that lead to negative emotions, the system can better assess and respond to the user's current emotional status.

Unlike negative emotions, positive states are usually not elicited through other driver behaviors, but rather influenced by nice surroundings [72] [73] and personal interactions with passengers [72] [74]. Moreover, drivers gave account of their ability to drive well and their car's performance features to cause positive emotions [72] [73].

2.4 Emotion detection in car

For effective human-vehicle interactions, it is essential to accurately, consistently, and efficiently detect the emotional states of drivers and passengers [53]. In the context of human emotion research in driving, several measurement techniques are employed. Desmet et al. [75] stated that existing measurement instruments can be divided into two general categories, psychophysiological measurement instruments and self-report measurement instruments. Li et al. [53] further classified these measurements into three categories: physiological measurements, behavioral measurements and self-reported scales.

2.4.1 Physiological measurements

As Li et al. [53] stated, physiological measurements involve capturing and analyzing biological signals from the body, such as heart rate or pupil dilation, to understand how emotions affect physiological responses. Physiological measures like heart rate variability, skin conductance levels, skin temperature, breathing rate, or EEG can be used to deduce driver states [76] [77] [78]. For example, heart rate gives an indication of the driver's state of arousal [79] [80]. Lower heart rates indicate a more relaxed state, while higher heart rates occur during high driver activation. Respiration rate is also connected to arousal states, slower and shallower breathing indicates a relaxed state whereas alerted or active states result faster breathing and indicate emotional excitement. Skin conductance levels are associated with measures of emotion, arousal, and attention[81]. EEG signals measured from the top of the scalp give information about the cognitive and emotional state of the user [82] [83].

However, according to Desmet et al. [75], physiological measures cannot be used to distinguish emotions since they only indicate the amount of arousal, which is part of emotion [84].

2.4.2 Behavioral measurements

Behavioral measurements focus on observing and analyzing how individuals act or react when exposed to emotional stimuli, such as changes in facial expressions or body movements. Most behavioural measurements are unobtrusive contactless technologies, such as audio-visual sensors, eye-tracking, and facial expression analysis, which are more likely to be accepted in cars due to their low initial barriers [85] [86]. In addition, detection of emotion from driving style, posture in sitting, and motion should be taken into consideration.

2.4.3 Self-reported scales

Self-reported scales, on the other hand, use questionnaires or surveys in which participants describe and rate their own emotional experiences in response to specific stimuli.

2.4.4 Other contextual factors

Emotions naturally arise in various situations, including during driving [4]. A driver's affective state is continuously influenced by environmental factors (such as road conditions and weather), situational factors (such as traffic conditions), and interpersonal factors (such as conversations and user interfaces). These factors cause the driver's emotions to fluctuate. Among these, situational factors, such as the specific circumstances drivers encounter, can enhance the accuracy of emotional assessments. For instance, a driver rushing to work might experience heightened anxiety and anger when faced with a traffic jam [53].

All in all, a system that considers emotion measurement in detail from different resources through multiple measurement methods is vital for understanding emotions. An in-car environment provides a great starting point for such systems, as users are confined to a limited space and all kinds of sensors are highly common in the interior of a modern car and widely accepted by users [4].

2.5 Emotion regulation in car

As noted by James [87], emotion regulation involves a wide range of both conscious and unconscious strategies aimed at modulating our emotional responses. These strategies can either amplify, sustain, or diminish various aspects of our emotions.

In the context of driving, car systems can employ various techniques to regulate emotional states and induce desired emotions. Common methods in driving-related emotion experiments include emotional video clips, traffic scenarios, and music. Siedlecka and Denson [88] categorize these emotion induction techniques into five primary types: situational procedures, visual stimuli, auditory stimuli, standardized imagery, and autobiographical recall. Moreover, emotional behavior itself can act as an emotional stimulus.

When it comes to emotion regulation, two primary strategies are highlighted. Emotion Regulation, where a target mood different from the current one is set as a goal; and Emotion Maintenance, where the driver is already in a suitable mood, and actions are taken to sustain it.

2.5.1 Visual stimuli

Vision is the dominant sense during driving, making visual methods the most prevalent for emotion regulation. Research by Siedlecka and Denson [88] indicates that visual stimuli are particularly effective in inducing basic emotions.

However, at lower levels of vehicle automation, using visual stimuli for emotion regulation may lead to potential distractions for the driver. This risk can be mitigated as the vehicle reaches higher levels of automation, allowing for greater flexibility in visual regulation techniques.

Current studies on visual regulation of driver emotions explore various approaches, including the use of ambient light, visual interventions, state feedback, and visual relaxation techniques.

2.5.1.1 Ambient light

Ambient light involves using cockpit illumination to regulate driver emotions [53]. Research indicates that ambient light can evoke various emotional responses, influenced by factors such as colors, brightness, positioning, and the driver's familiarity with the system [4] [89] [90] [91]. Due to the complexity of this strategy, it will be discussed in detail in the following section.

2.5.1.2 Visual intervention

Visual interventions are inherently distractive, so their use while driving must be carefully planned [53]. These interventions, such as film clips or static images, are chosen to evoke specific emotions. For example, a dramatic movie scene might create tension, while a serene landscape photo could foster calmness.

2.5.1.3 State feedback

State feedback refers to the visual display that allows drivers to understand their current emotional states clearly. Researchers' studies found that direct feedback on the detected drivers' states had little value for emotional regulation because visual state feedback could amplify the driver's negative emotional states, which was unacceptable to the driver and needed to be avoided examined the visual state feedback of drivers' negative emotions [92] [93]. Besides, participants preferred to receive only safety-critical notifications of the driver's state [93]. Thus, it is feasible to blatantly intervene when the possibly dangerous emotional state is likely to occur, such as providing a simple notification, telling the driver to take a break, and distracting the driver from the source of negative emotions, as well as presenting a positive notification to decrease drivers' negative emotions [94] [92] [93].

2.5.2 Auditory stimuli: Adaptive music

Auditory stimuli can achieve similar effects through sounds such as music or the comforting voice of a smart car assistant, both of which can soothe or energize the driver [53]. Dibben and Williamson [95] reported that 70% of drivers listen to music while driving, and since the introduction of the first car radios, listening to music has remained one of the most popular activities among drivers. The concept of emotionally adaptive music in driving contexts to positively influence the driver's emotions has been explored in numerous studies [96] [72] [97] [98] [38]. Music, regardless of its type, generally has a calming effect on the driver's state and enhances driving behavior [99].

Previous research [72] [97] [98] shows that positive emotional reinforcement occurs with preferred and familiar music, when singing, and when improvising for musical individuals. In contrast, complexity, dissonance, and unexpected sounds generally have a rather negative impact [100]. However, the perception of music and accompanying emotions is highly subjective. Thus, one piece of music can hardly be classified into a category of emotions it will induce. As a solution to this uncertainty problem, approaches have emerged to annotate music titles with crowd-sourced values of arousal and valence, such as the DEAM Database for Emotional Analysis in Music [101]. Researchers are increasingly relying on such databases instead of subjectively selected music to recommend music. Another challenge in emotion regulation through music is the recommendation process itself. While offering adaptive music to influence emotional states is an effective technique, it may lead to user resistance if they feel manipulated. However, subtly recommending calming music to drivers in high-arousal states can help them relax and interrupt the cycle of emotional reinforcement caused by self-selected music [53].

These findings are crucial for designing music recommendation systems and emotion regulation strategies, as they highlight how selecting appropriate music can foster positive emotional responses while avoiding the induction of negative ones. In order to regulate emotions of users in car, a contextual mood-based music recommending system capable of regulating the driver's mood will have to be designed, which uses various sources of information for tuning their recommendations.

2.5.3 Olfactory stimuli: Aroma

Lenochova et al. [102] stated that human psychological functioning, including perception, mood, cognitive processes, and behaviors, can be influenced by aromas. Johnson [103] also noted that aroma affects human performance across various contexts. Research suggests that certain aromas, such as peppermint and cinnamon, can enhance driving performance by maintaining alertness during prolonged driving, potentially reducing accidents and fatalities [104] [105].

The sense of smell is notably sensitive and can quickly detect aromas [104]. Mastafu et al. [105] found that aromas like lavender and vanilla can positively affect drivers' emotions, leading to relaxation, increased comfort, alertness, and a sense of freshness. However, it is also important to note that some individuals may prefer a non-aroma environment [105]. Additionally, Dmitrenko et al. [106] discovered that aromas such as rose and peppermint can shift drivers' emotions toward a more positive valence.

2.5.4 Haptic Stimuli

Temperature control has been demonstrated to alleviate the effects of high arousal, creating a more comfortable and calming environment within the vehicle, thereby enhancing overall user satisfaction [53]. Effective temperature management can mitigate high arousal [107] [108]. Schmidt et al. [76] found that cool airstreams can reduce low arousal, increase alertness, and stimulate sympathetic activity, which improves driving performance and acceptance. Additionally, there is an intriguing link between temperature and color perception. Research conducted in a light laboratory indicated that room temperature was perceived differently based on the color of the lighting. Specifically, the room appeared warmer under yellow light compared to blue light [109].

2.6 Light

Light influences more than just visual perception, which also impacts mood and emotion. Since lighting is a crucial aspect of this project, I have conducted extensive research on its effects. Although it falls under the broader category of emotion regulation, it warrants a standalone section for clarity and emphasis.

Research indicates that colors can affect emotional states [110] [111]. Blue light, for instance, is effective in treating sleep disorders and depressive mood disorders, particularly winter-based seasonal affective disorder (SAD) [112] [113] [114] [115].

Light affects mood by influencing the circadian system, which involves the interaction between human biorhythms and the natural environment [116] [40]. Specifically, light intensity impacts melatonin secretion, a hormone related to alertness [40].

Colored lighting is increasingly used in public spaces to reduce behaviors like suicide and anti-social activities, though more research is needed to confirm its effectiveness [113]. The emotional impact of lighting adds value when harmonized with user scenarios, influencing emotions such as anxiety or stress through changes in brightness, color, placement, and behavior [117] [91].

Light positively affects both cognitive [118] [119] and physical [120] functions in healthy individuals. For example, it can accelerate wound healing, reduce migraine and tinnitus symptoms, and alleviate reading disorders [113]. In addition, qualitative and quantitative aspects of workplace illumination are of paramount importance in determining employee productivity, performance, and well-being [121] [122] [123].

2.6.1 Light dynamic pattern

Ambient light's dynamic behaviors are often designed to warn or alert drivers, providing immediate responses and preventing fatigue [124]. Subjects responded more positively and less attentively to smooth dimming lights, while tension increased with "sudden-high frequency" patterns, similar to the effect of flickering lights, which decreased user satisfaction [40].

According to ambient light design guidelines [124], Blink, Fade, and On patterns, where the entire lighting is controlled simultaneously, are preferred over individually controlled patterns like Collide, Spread, and Move. Fade behavior was seen as unobtrusive and more advanced compared to the smooth blink.

Guidelines for dynamic ambient lights include [124]:

1. Discrete blinking lights caused the highest levels of alertness and are suitable for urgent notifications.

2. Smooth blink is appropriate for non-urgent notifications as it feels less intrusive and energizing than discrete blinking.

3. On behavior, where the light turns on without a dynamic pattern, scored high in satisfaction and was seen as the most relaxing.

4. Collide, Spread, and Move behaviors had lower satisfaction scores. Among them, Spread was seen as more cutting-edge, obtrusive, and interesting, and it evoked more energy, making it suitable for alerts that need to be attention-grabbing.

2.6.2 Light Placement

Considering the project aims to implement solutions with minimal cost, I will maximize the use of existing in-car ambient lighting. Notably, Caberletti and his team investigated whether subjects' emotional responses would vary depending on light placement, based on self-reports. The study suggested design guidelines for placing lights to induce the desired mood, which could be useful for future modifications [125].

2.6.3 Light colors and brightness

2.6.3.1 Information transmission through colorful lights

Research has utilized different light colors to convey signals [91] [90]. Red lights are commonly used to warn drivers, with urgency indicated by blinking frequency or additional colors like yellow or amber for less urgent warnings. Colors outside the red-yellow-green spectrum, such as purple, blue, or white, can direct attention or display non-safety-related information like temperature or battery status [91] [90].

Participants reported that orange light, due to its similarity to red, indicated something was wrong and heightened their awareness, although it was not very comfortable [89]. In contrast, blue light influenced their emotional state and driving performance, making them feel more relaxed [89]. Blue lights were also effective in reducing errors and heart rate, demonstrating a calming effect on drivers [89] [90].

2.6.3.2 Colors on emotion

Researchers have long studied the effect of color on emotion [126] [127] [128]. Valdez and Mehrabian [126] generalized emotional patterns to different colors by assessing pleasure (valence), arousal, and dominance. They found that brighter and more saturated colors generally elicited greater pleasure, with this relationship being non-linear. Pleasure was more influenced by brightness than by saturation. Colors like blue, blue-green, green, red-purple, and purple elicited higher pleasure levels compared to green-yellow, yellow, and yellow-red.

Wright and Rainwater [129] found that higher color saturation and brightness correlated with increased arousal. Valdez and Mehrabian [126] elaborated that arousal increased linearly with color saturation and had a ladle-shaped relationship with color brightness. Green hues (green-yellow, blue-green, and green) elicited the highest arousal reactions.

Guilford and colleagues [127] [128] found that the most preferred colors were blue, green, purple, violet, red, orange, and yellow, which aligns with the light color preferences identified in Kim's study [40]. Additionally, brighter colors (e.g., whites, light grays) are generally more pleasant, less arousing, and less dominance-inducing than darker colors (e.g., dark grays, blacks) [126] [127] [128] [130]. This finding is consistent with research indicating that subjects tend to have better moods in brighter light settings [131].

Conclusions from color psychology have been validated in experiments with a limited range of light colors, supporting the applicability of color-guided mood theories to the effects of lighting on mood in automotive environments.

2.6.3.3 Colorful lights on emotion

The effect of lighting color on health, well-being, mood, and performance has been extensively studied [113]. Most research focuses on the calming effects of blue light, which has been scientifically validated [40] [90] [89] [4] [124]. However, there is no consensus on the emotional impacts of different light colors. For instance, blue and orange-enriched lights have distinct emotional effects, but a theoretical framework linking specific light values to emotional responses is lacking.

Current research offers some insights. For example, A study conducted by Kim [40] found that subjects generally preferred blue, warm white, and cool white lights over red and green, with red light causing more tension. Orange-enriched white lighting creates a luxurious atmosphere, while blue-enriched white lighting enhances alertness [125] [132]. Åkerstedt et al. found that bright, blue-enriched car interior lighting increases morning alertness, with higher color temperatures (6500K) being more effective than lower ones (3500K) [133] [134] [135] [136].

While specific lighting colors have been shown to influence emotions, more research is needed to develop precise methods for using a broader range of colors of lights to induce desired emotional states. However, the color effects on emotions could be generalised on the colorful lights as well.

In general, evidence available from studies that have used a variety of color stimuli (including colored objects, rooms, or clothing), when interpreted within the PAD Emotion Model, tends to be consistent with the results obtained in the studies by Valdez and Mehrabian [126]. Valdez and Mehrabian tentatively concluded that their results could be generalized to color stimuli encountered in everyday situations [126]. Although these are speculative, they may help identify promising avenues for developing a theoretical rationale to explain emotional reactions to light's colors. Given the limited color samples in light experiments, I propose applying the emotion induction theory from color studies to the field of ambient lighting colors.

The light will be quantified by the PAD values. Valdez and Mehrabian [126] used the abbreviations P for pleasure, A for arousal, and D for dominance, the effect of brightness is summarized as follows:

$$\text{Brightness} = +P - A - D \tag{1}$$

or

$$\text{Darkness} = -P + A + D \tag{2}$$

Not only color can be measured by PAD values, emotions can be measured through equation with PAD model as well. For example, Mehrabian and O'Reilly [137] obtained Equation (3) for aggression, and Russell and Mehrabian [58]obtained Equation (4) for anger.

$$\text{Aggression} = -0.36P + 0.20A + 0.28D \tag{3}$$

$$\text{Anger} = -0.74P + 0.36A + 0.09D \tag{4}$$

By using the PAD values and those equations, I can systematically evaluate how different lighting conditions impact emotional states and how to adjust different light values to induce the desired states. This approach not only enhances the understanding of the psychological effects of light but also aids in the practical application of ambient lighting to influence mood and behavior in various settings.

2.7 Summary

While much research has focused on leisure experience design during commuting, these studies often assume AVs context [13] [30] [14] or target on passengers [46] [24] [45] [29] [48]. However, there are still many technical and organizational issues to be addressed before reaching the fully autonomous driving [12]. In fact, several experts expressed their belies that the fully autonomous driving will not arrive in 10 years in the interviews. Therefore, there is a gap between the conceptual solutions and the real implementation for leisure experience design. Additionally, only few studies address driver-centric leisure activities. This project aims to bridge these gaps by focusing on the driver's experience in partially autonomous context.

Additionally, there have been numerous proposals to rethink the commute and turn it into a time for enhancing human well-being through various activities such as stress management, fitness, socialization, gamification and more. Many of these innovative design innovations falls under the categories, such as *Car as a caretaker* [8] [26] [13] [27] [51] [52], *Car as a space for stimulation* [49] [47] [29] [45] [46] [24] [48] [30], *Car as a space for social relatedness* [31] [32]. However, designs for *Car as a space for transition* between home and work remains largely unexplored. This projects will contribute to this area by specifically helping drivers prepare for the next stage of their day through emotion-based multisensory experiences.

Furthermore, a comprehensive research effort has been conducted to explore strategies for both emotion detection and regulation. Understanding emotions needs a system that considers emotion measurement in detail from different resources through multiple measurement methods [4]. Thus, the design in this project will integrate the physiological measurements, behavioral measurements, self-reported scales and other contextual factors in the emotion detection system.

Lastly, there are many studies focused on emotion-based affective driving [138] [4] [42]. Additionally, numerous studies have explored various emotion regulation strategies, such as music [99] [97], aroma [105] [104] [106], ambient lights [116] [115] [121] [109] [111], and haptic senses [51] [16]. However, none have combined multiple strategies into a single in-vehicle system. This design project will integrate these strategies to create a comprehensive multisensory experience. Regarding the visual strategies, while specific lighting colors have been shown to influence emotions [125] [132] [40], more research is needed to develop precise methods for using a broader range of colors of lights to induce desired emotional states. This project will generalize the color effects on emotions on the colorful lights. This remains one the limitations of this project.

In summary, the contributions will be:

- **Driver-Centric Leisure Experience in conditional AVs context:** While much research has focused on leisure experience design during commuting, these studies often assume an automated driving context or target on passengers. However, few studies address driver-centric leisure activities. The work fills this gap by focusing on the driver's experience in conditional AVs context.

- **Transition Between Home and Work:** Designs under the transition UX theme have been largely unexplored, and the work contributes to this area by specifically helping drivers prepare for the next stage of their day through emotion-based multisensory experiences.

- **Multisensory Experience:** Although many studies have explored various affective strategies, none have combined multiple strategies into a single in-car system. The design integrates these strategies to create a comprehensive multisensory experience.

3

Method

This study adopts the Research through Design (RtD) approach, a methodology that generates new knowledge by iteratively engaging with the design process to analyze the present state and propose an enhanced future state through design interventions [139]. RtD involves a process of deep reflection and iteration, where researchers gain insights by understanding users, identifying problems, and exploring the context in which improvements are possible. This methodology is particularly well-suited for investigating complex, open-ended problems, as it merges design practice with theoretical reflection to explore innovative concepts, methods, and applications.

In the initial phase of the design study, I conducted expert interviews within the company to grasp the core essence of Polestar, which helped establish the design guidelines for the entire project and set the criteria for selecting design concepts in the subsequent workshops. After developing the design concept *Commuting therapy*, I used an AR car simulator to evaluate the results through two assessment tools: the Product Emotion Measurement (PrEmo) and the User Experience Questionnaire (UEQ). Finally, I conducted a semi-structured interview to gather further insights. The chosen evaluation method and the questions for the semi-structured interviews were structured based on Jordan's framework of product pleasures.

This chapter introduces the design framework that outlines the overarching guidelines for the project. It also presents several detailed steps within the overall Research through Design (RtD) methodology used in the study design.

3.1 Design framework

The design framework used in this study is Jordan's Four Product Pleasure model [140]. Specifically, the four pleasures of the product are physio-pleasure, socio-pleasure, psycho-pleasure, and ideo-pleasure. Physio-pleasure is derived from sensory experiences, including touch, taste, smell, and feelings of sexual or sensual pleasure. Socio-pleasure arises from the enjoyment of social interactions and the company of others. Psycho-pleasure is obtained through the successful completion of tasks, highlighting how a product can facilitate task completion and create a satisfying experience. Ideo-pleasure relates to the aesthetics of a product and the values it embodies. Considering all these four aspects helps me design pleasurable experiences to enhance the user experience during daily commutes.

I applied Jordan's Four Product Pleasures model [140] throughout the UX design process, from assessing current situations, identifying design opportunities, implementing design interventions, to evaluating the outcomes. The integration of the framework into my design process is outlined as follows:

1. **A desired experience:** Propose a desired pleasurable leisure experience for daily commuting.

2. **Current situation:** Look into the current commuting situation, What pleasures are associated with the current commuting experience?

3. **Design opportunities:** To identify design opportunities for achieving the desired experience, I can employ three strategies: strengthen existing needs, introduce new needs, or reduce needs that are negatively impacted by the current product [57]. Additionally, I can further explore which pleasures can be enhanced or introduced.

4. **Design intervention:** Take design interventions to achieve the desired experience.

5. **Evaluation:** Evaluate the final design solution by assessing the extent to which it fulfils the desired product pleasures.

3.2 Study design

3.2.1 Preliminary Expert Interview Study

In the initial phase of my study, I conducted a series of semi-structured interviews to delve into the essence of Polestar. The questions were structured around key themes such as brand values, design philosophies, target users, emerging technology trends, and the future of Polestar. These interviews also aimed to explore participants' expectations and visions for future leisure experiences with the Polestar brand.

3.2.1.1 Process

I conducted a total of 13 interview sessions, including 12 individual interviews and 1 group interview, each lasting approximately one hour. To ensure comprehensive data collection, all interviews were recorded audio, and some of the online sessions were also recorded video. My interview process involved a primary interviewer and an observer. The main interviewer was responsible for posing the questions, while the observer focused on noting nonverbal cues, taking detailed notes, and contributing additional questions towards the end of each session.

The interview data were promptly transcribed during or immediately after each session to preserve the accuracy of the participants' responses. The transcriptions were then broken down into numerous short notes that capture the significant statements made by the participants. For the analysis, I used affinity diagramming to systematically categorize and identify common themes in the collected data.

3.2.1.2 Participants

The participants consisted of sixteen employees from various departments within Polestar. The aim was to gain a comprehensive understanding of Polestar's design philosophy from diverse professional perspectives. The objective was to gather insights that would establish a guideline ensuring the project's alignment with the Polestar brand and to enhance its possibility for real-world production.

The participants represented a broad spectrum of expertise:

User Experience Design Team: 8 experts
Engineering and Technical Team: 3 experts
Interior Design Team: 3 experts
Innovation Design Team: 2 experts

These interviews were designed to harness the specialized knowledge and viewpoints from across these different fields, thereby enriching my approach and paving the way for future project implementation within Polestar. The general questions are attached in the appendix, but I revised several questions according to different expertise of the participants I interviewed.

3.2.1.3 Results

The results of this phase were used to find the common consensus of core value and leisure experiences within Polestar.

In addition to using these findings as guidance for the development of the future design of leisure experiences, they also provided me with a good understanding of the essence of Polestar. These perspectives were translated into references that were utilized in the next study phase, Ideation workshops, to inspire the participants and help me to narrow down the ideas.

The essence of Polestar encompasses key topics such as design philosophy, design implementation, brand positioning, and target users. Experts described Polestar as a sophisticated, luxurious, high-performance, and sporty brand. The UX design manager emphasized that Polestar aims to develop simple products powered by complex technologies, making advanced features intuitive for users. He highlighted that Polestar prioritizes seamless user experiences over flashy or gimmicky functionalities. The focus is on integrating sophisticated technology in a way that feels natural and effortless for the user, ensuring that every interaction is smooth and straightforward.

Most experts emphasized that Polestar is a design-driven company, prioritizing design in its decision-making processes. They expressed confidence in Polestar's UX system, frequently using terms such as "simple," "minimalistic," and "Scandinavian" to describe its design language. The digital design style is characterized by phrases such as "reduced interface," "big and bold buttons," "scroll forbidden," "cutting corners," and "simple but intuitive," with an emphasis on distinctiveness. An expert stated that Polestar's products are often compared to Apple products, focusing on minimalism, technology-centric features, and excellent user experiences. The company maintains strict control over aesthetics and errors, allowing only two font sizes and five colors in the UX system, without permitting user variations in color.

Many experts noted that Polestar's target user group overlaps with that of Apple products, consisting of technology enthusiasts eager to explore new innovations. For example, these users buy Vision Pro not necessarily to solve problems, but to experience cutting-edge technology. Other experts also envisioned tech-driven car enthusiasts, likely cool young individuals with a strong interest in technology. Given the price point of Polestar cars, the target age group has been adjusted to 30-40 years, aligning with the affordability of Polestar products. This demographic is often characterized as "middle-aged individuals with a strong interest in technology and refined taste" and "affluent individuals who value well-crafted products with exceptional quality and performance." Polestar aims to serve these discerning customers who appreciate the seamless integration of advanced technologies into their vehicles.

When implementing designs in Polestar vehicles, two key factors are prioritized: market needs and investment control. Market demand is the driving force behind design, which is essential to align new features with consumer preferences, though predicting these needs can be challenging. Additionally, the effective management of financial resources ensures that investments in design and technology deliver value. A notable example is the "Breath" project, a digital app developed for in-car deep breathing exercises, which averaged two minutes of user engagement. This app was integrated into Polestar cars and downloaded by over 1000 users, showcasing how market needs and controlled investment can drive successful project implementation.

Experts in the automotive industry are dedicated to staying ahead of cutting-edge technological trends, ensuring they provide the most innovative and refreshing insights. Key themes frequently mentioned by these experts include:

1. **Artificial Intelligence**: Artificial intelligence has made significant strides across various fields and has become so prevalent that every expert I interviewed acknowledges its impact and anticipates its crucial role in enhancing user experience in the automotive industry. AI enables more precise contextual usage and tailored personal experiences in cars. However, there was debate among experts about whether AI functionalities, which are already feasible on mobile phones and computers, are necessary in automotive environments.

If AI is integrated into vehicles, the challenge lies in distinguishing its applications in a car from those on other devices. The goal is to ensure that AI provides unique, valuable benefits specific to the driving experience.

2. **Autonomous driving**: Autonomous driving is a pivotal topic in the realm of technology, with widespread belief that, despite the common assertion that it's just around the corner, it still has a considerable journey ahead. Experts agree that complete autonomy is unlikely to be realized within the next 20 years. Currently, Polestar's autonomous driving capabilities fall between Level 3 and Level 4, which must be factored into the design of in-car leisure experiences.

3. **Human-machine interface**: The interaction between humans and machines has evolved beyond traditional digital or physical screens to include a variety of advanced technologies. These include gesture recognition, voice recognition, head or eye tracking, proximity-based wake-up systems and so much more. The accuracy of these input and recognition methods is continually improving, with reaction times becoming increasingly swift. Designers are focused on seamlessly integrating these interactive technologies to optimize their effectiveness and minimize distractions across different scenarios, particularly for drivers. This approach aims to reduce cognitive load and enhance overall user experience.

4. **Health monitoring and management system**: The Polestar 4 is equipped with a driver monitoring camera that tracks the driver's attention and fatigue levels. This camera is mounted above the dashboard, aimed directly at the driver's face, and provides real-time monitoring of the driver's eye activity and blinking frequency. By analyzing these data points, the car system can determine whether the driver is focused on the road or showing signs of fatigue. Additionally, the Polestar 4 features a handwheel monitor sensor designed to detect if the driver's hands are positioned correctly on the steering wheel. This function is optional and can be activated at the driver's discretion to reduce user resistance.

5. **Virtual Reality and Augmented Reality**: Virtual Reality (VR) and Augmented Reality (AR) technologies have significantly transformed how information is presented, offering users immersive experiences in various domains. For instance, Meta's Oculus Quest (Meta, 2023) provides a fully immersive VR experience for gaming and virtual meetings, while Microsoft's HoloLens (Microsoft, 2023) utilizes AR to overlay digital information onto the physical world, enhancing tasks such as remote assistance and interactive training. Experts highlight that Polestar is actively developing AR glass, though its specific functionalities and use cases are still under exploration. Integrating AR and VR into the design of in-car leisure experiences is crucial, driven by both technological trends and Polestar's substantial investment in these technologies, which offers a solid foundation for growth. For example, envision an AR navigation system akin to the one developed by WayRay (WayRay, 2023),

which projects directions directly onto the windshield, or a VR entertainment system inspired by HTC Vive (HTC, 2023), providing immersive content during autonomous driving. These innovations have the potential to significantly enhance the user experience within the vehicle.

When discussing the leisure experience in cars, experts highlighted numerous innovative features that go beyond traditional offerings such as video streaming, gaming, and karaoke. For example, Tesla offers a fireplace mode, where users can enjoy a virtual fireplace displayed on the center screen with the soothing sounds of crackling wood. Another notable feature was from the now-defunct brand Hiphi, which provided a charging port on the car roof for camping devices. Polestar 4 has introduced an animal mode, allowing users to leave their pets in the car with the climate control running in auto mode. Many experts agreed that providing unique features not available on mobile phones would significantly enhance the in-car leisure experience. Common themes mentioned in this context include wellness and well-being, emphasizing the importance of creating a relaxing and enjoyable environment within the vehicle.

1. **Entertainment**: Some experts anticipate the development of more immersive and sophisticated entertainment systems for music, gaming, and videos in cars. For instance, they envision features like theatre mode for a cinematic experience, connectivity between cars for multiplayer gaming, communication, and even driving competitions. These advancements aim to transform the in-car experience, making it more engaging and interactive, and providing unique entertainment options that go beyond what is available on mobile devices.

2. **Driving experience**: Polestar started as a driver-centric brand and continues to emphasize the driving experience. Many users view driving as a source of joy and stimulation. For instance, Mercedes has introduced a feature that allows drivers to improvise songs using the steering wheel while driving (Mercedes-Benz, 2023). This illustrates the potential for further innovations to enhance the driving experience. By integrating advanced technologies and creative functionalities, Polestar can continue to elevate the joy of driving, making it more engaging and enjoyable for users.

3. **Mindfulness**: Some experts have noted that our daily lives are inundated with information, creating a constant influx of data to process. As a result, many drivers seek moments of mindfulness while on the road, desiring a break from the technological world. They appreciate features that offer mindfulness relaxation or meditation, which can benefit their mental health. Integrating these calming and restorative experiences into the driving environment can help drivers detach from the constant stream of information and find tranquility, enhancing their overall well-being.

4. **Wellness and well-being**: Some experts have observed that our daily lives are already saturated with information, leading many drivers to seek moments

of mindfulness while driving. They desire opportunities to detach from the technological world and enjoy relaxation techniques that benefit their mental health, such as mindfulness exercises or meditation. These features can provide valuable moments of tranquillity in the constant flow of information. However, the UX manager noted that in his years of experience with health monitoring, the typical solutions — such as mindfulness exercises, ambient lighting, or calming music—often need to be chosen with caution. These elements must be carefully integrated to ensure they enhance the driving experience without becoming distractions or detracting from overall safety.

When discussing the future of Polestar cars, most experts agree that vehicles will continue to serve primarily as tools for transportation. The future selling point of cars is anticipated to be their role as a private space, which is essentially a flexible, mobile extension of one's home. Experts predict that, even in a decade, users will still need to connect their phones to their cars to access music and other functionalities. After exploring intricate features and decorative gimmicks, car interiors and functionalities should refocus on what genuinely matters to drivers. Streamlined, intuitive designs that prioritize practicality and user experience are expected to become central to future automotive developments.

Additionally, there are challenges in advancing UX design due to the need to accommodate different platforms across various generations of cars. For example, the Polestar 4 is built on Geely's SEA platform, which is tailored for the Chinese market, while other models are based on Volvo's SPA2 platform. This discrepancy requires designers to ensure a consistent user experience across diverse platforms, presenting a significant challenge. Maintaining uniformity in UX design while catering to platform-specific requirements is crucial for delivering a cohesive and seamless experience for all users.

3.2.2 Ideation workshops

One form of innovative methods is creative sessions, such as design workshops, where participants (users) are invited to generate ideas and communicate their thoughts [141]. I organised two workshops, both within and outside the company to get diversified creative thoughts. Subsequently, I identified several fields that are most promising in the automotive leisure experience based on previous research.

1. **Car as a space for transition**: The state of experiencing calmness and reduced stress, often achieved through restful activities that soothe the mind and body.

2. **Car as a space for stimulation**: The feeling of heightened energy and enthusiasm, typically resulting from engaging in stimulating or thrilling activities.

3. **Car as a space for social relatednee**: The sense of connection and belong-

ing with others, derived from meaningful interactions and shared experiences.

4. **Other**: Anything participants can conceive, ensuring their thoughts are unrestricted and encouraged to explore freely.

The mutual methodology I used in different ideation workshops is brain writing. Brain writing is a collaborative ideation technique in which participants silently write down their ideas on a specific theme and then pass them on to others to build upon. However, unlike the traditional brain-writing technique, which minimizes verbal communication, I allowed participants to explain their ideas verbally to build a mutual understanding.

Building on previous research, I directed my design towards creating a multi-sensorial experience within intelligent cockpits. In my first workshop, I facilitated sensory exploration by encouraging participants to engage with various sensations, particularly emphasizing tactile and olfactory experiences. The second workshop adopted a broader context beyond automotive applications, encouraging diverse and unexpected ideas. Moreover, the second workshop built upon insights and outcomes derived from the initial session.

3.2.2.1 On-site workshop

The on-site workshop took place in a dedicated room adjacent to the car show hall at the Polestar HQ. This location allowed participants to seamlessly transition between the workshop discussion environment and the real-world car scenario, facilitating a more immersive experience. I sent out invitations and prepared various refreshments, including drinks, snacks (candy and chocolate), as well as necessary materials such as sticky notes, whiteboards, and pens. Additionally, I focused on engaging different sensations, particularly tactile and olfactory experiences. To facilitate this, I provided various scents and Arduino components (Soma bits) to enhance sensory exploration.

Figure 3.1: Workshop preparation

There were our participants took part in the session: three from the User Experience Design team and one from the User Experience Attributes team. All participants are avid drivers with a strong passion for technology and a deep understanding of cutting-edge advancements.

I began the workshop with a 15-minute lightning talk, presenting PPT slides to inform participants about the project's background, objectives, latest technological advancements, academic research, and methodologies. During this session, I also outlined the day's agenda, goals, task briefs, and workshop rules, emphasizing a non-judgmental and egalitarian environment where generating a quantity of ideas took precedence over immediate quality.

Following this, I started an icebreaker exercise designed to stimulate the senses through the Soma experience, lasting 40 minutes. Firstly, I guided participants to do a body scanning to figure out what sensation was stood out at the moment, and used body map to visualise the feelings. This was done to activate the body senses in order to invite participants to pay more attention to their body senses while ideating in the car context. Then, I asked participants to move to the show hall, where they could sit inside the Polestar 2 to practice breathwork, acupressure, feldenkrais, and meditation as guided exercises. After that, they went back to the original room to explore the soma bits for different sensory responses. In the following, they redrew the bodymap. In the end, I organised a brief discussion where participants shared their body maps and favourite exercises.

The main part of the workshop focused on the commute scenario, situations that could take place in the context of transition between home and work, especially stop-and-go traffic jams. The task was to come up with new ideas for leisure experience that could enhance the commuting experience in general or in a specific situation. Thus, they were introduced to the project scenario:

" It's Tuesday evening, and Eric is heading home from work, a journey that typically takes him about an hour. However, today the traffic is unusually heavy, and he finds himself in a stop-and-go situation for what seems like forever. What can I do to make the mundane commuting experience more pleasant?"

The methodology I used for the workshop is called brainwriting. Brainwriting is a collaborative ideation method where participants write down their ideas rather than verbally sharing them, fostering creativity and inclusive participation in team settings. Brainwriting was structured in several directions that I found to be the most promising in the academic field, which are relaxation, social aspects, and exitement. However, I did not want to limit the thoughts of my participants, so I added one more category, which is called "Others". In order to help participants understand different categories more profoundly, I printed and hanged the pictures and definitions of different categories from Desmets' 13 fundamental physchological needs on the wall.

There were two rounds of brainstorming. In the first round, participants were asked to think about an in-car leisure experience that transforms the boring, negative experience to an enjoyable, positive experience. based on the story and the pain points. They were able to write, draw, or even act out (Body storm) with the artifacts to ideate at least 3 ideas within 6 minutes. At the end of each session, they took turns explaining the idea and started brainstorming in another category. They were encouraged to build on the ideas of other participants.

In the second round of brainstorming, participants were asked to come up with a final idea in 5 minutes, consider merging, integrating or building on their past ideas and the ideas of others they liked. In the end, they were asked to explain the ideas in turn.

The brainstorming workshop yielded significant insights that will shape the upcoming online workshop and the future direction of this project. The primary objective was to harness collective creativity and identify innovative solutions to enhance leisure user experience in Polestar vehicles.

Several design directions emerged during the session:

1. **Car as a space for transition**: To enhance relaxation and comfort, the participants suggested features such as reclining or massage seats and mood lighting, creating a "Yoga Mode" for the vehicle.

2. **Car as a space for stimulation**: Participants proposed various ways to increase excitement during the drive. Hands-on activities could include engaging in physical or digital construction projects, such as woodworking or programming Mindstorms kits, ranging from simple to complex tasks. Digital interaction opportunities for music creation and programming were suggested, catering to tech enthusiasts. Additionally, driver-centric features focusing on fun, stimulation, and speed were highlighted to enhance the driving experience for automotive technology enthusiasts.

3. **Car as a space for socialization**: In exploring socialization within the vehicle, participants proposed various innovative approaches to enhance interactions among occupants, between vehicles, and with people outside the car.

    (a) **Co-Experience Among Occupants**: To enrich the shared experience within the vehicle, participants suggested facilitating intellectual engagement through stimulating conversations and interactive questions. Collaborative digital or physical projects and karaoke sessions were proposed to encourage teamwork and fun. Additionally, integrating window displays to engage with landmarks and provide context could enhance the overall experience for all occupants.

(b) **Connection Between Cars**: For interactions between vehicles, the focus was on facilitating casual communication during traffic jams. Ideas included implementing features that allow vehicles to share emotions or offer advice through vehicle labels, thereby improving understanding of road conditions and fostering connections among drivers. This could also help in enhancing communication among commuters and improving overall traffic flow.

(c) **Connection with People Outside the Car**: To strengthen connections with people outside the vehicle, participants suggested enhancing family and friends interactions. This could involve features for playing games with children, connecting with nearby friends for social events, or planning activities together. Options for signalling social availability, such as through a social calendar, were discussed. Additionally, managing interruptions from work and scheduling calls during commutes were considered to improve overall social and personal interactions.

(d) **Others**: Proposed features include food delivery to the car and grocery pickup during traffic jams, enhancing convenience and efficiency on the road.

3.2.2.2 Online workshop

Based on what I got from the last session, I conducted another online workshop to diversify and deepen the ideas. I designed the process and prepared different layouts of boards in Figma.

To gather diverse perspectives, I recruited six external participants, offering film tickets as incentives. my selection intentionally focused on individuals with a design background to leverage their creative expertise. Among the participants, there were three User Experience (UX) Designers, one User Interface (UI) Designer, and one Product Manager who previously worked as a UX Designer. Additionally, I included two students: one majoring in Industrial Design Engineering and the other in Interactive Design and Technology.

In my Figma workshop, I provided participants with a quick guide to help them use various tools to express their ideas effectively. I started by introducing everyone, outlining the goals, agenda, and rules of the meeting. I defined "leisure experience" as follows:

"Leisure is time off, free time, and sweet freedom from the demands of work. It's like playtime for grown-ups, a break from commitments like work or school."

Instead of limiting creativity to automotive themes, I encouraged participants to explore general leisure experiences. I asked them to consider what they usually do for leisure in their daily lives or what they aspire to do for leisure in the future. I then guided them to think about how technology mediates leisure experiences. For instance, I asked about new possibilities or opportunities that technological devices have introduced into their leisure activities, and what innovations they would like to see.

Next, I conducted a quick recap of in-car technologies from four perspectives: Human-Machine Interaction, AR/VR Displays, Emotion Recognition, and Health Monitoring. Following this, I narrowed the focus to leisure experiences within the automotive context, introducing the commuting scenario. I also presented academic design ideas related to mood regulation, fitness/well-being, and music improvisation, aiming to inspire participants rather than restrict their creativity to avoid similar themes.

After providing this background information, I began the main brainstorming session, which lasted 40 minutes. I set up six boards with different themes for six rounds of brain-writing, each round lasting up to 5 minutes. Participants were tasked with generating at least three ideas related to the theme on their assigned board. After each round, they switched boards and built upon each other's ideas.

For this workshop, I included two new themes based on the most interesting developments from the previous session:

Co-experience within occupants: Collaborative activities, both physical and digital, among car occupants.
Connection with people outside the car: Investing valuable time with children or friends during the commute.

After brainstorming, participants had 10 minutes to explore and review others' ideas on the boards, using digital stamps to express their thoughts or feelings about specific concepts. This allowed them to synchronize information, refine, and build upon their favourite ideas. Finally, they were asked to develop one final idea they found most compelling and share their insights with the group.

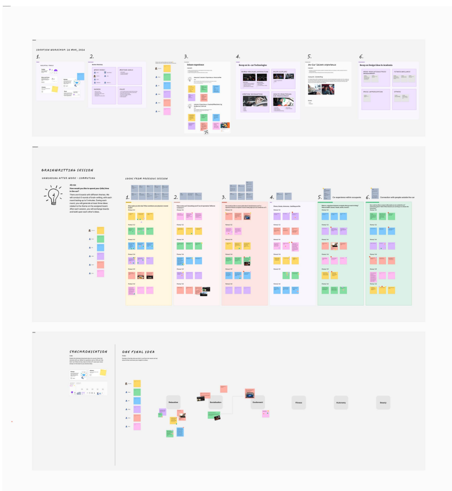

Figure 3.2: Online workshop

The workshop was highly productive, generating a rich array of ideas. The participants freely explored concepts beyond practical constraints, resulting in many unconventional and imaginative suggestions. Although they were instructed to develop only one key idea in the end, the range of provocative and non-traditional ideas generated before was striking and added significant value to the exploration process.

1. **Car as a space for transition**: The workshop explored several approaches to enhancing relaxation within the vehicle. One group of ideas focused on creating a calming atmosphere through sensory experiences. This included the planned release of different aromas and the adjustment of hot/cold air to evoke environments such as a rainforest or a sandy desert. Another suggestion was the customization of aromatic scents to improve air quality and adjust mood.

   Participants also proposed implementing features to aid mental well-being and stress relief. For instance, a guide that prompts meditation, deep breathing exercises, and personal reflection logs after a long day was discussed. An on-screen reminder with engaging animations for deep breathing was suggested, with the possibility of integrating breathing sensors to detect irregular patterns indicative of stress. Additional ideas included meditation aids and soothing music, such as white noise, to further enhance relaxation.

2. **Car as a space for socialisation**: In exploring socialization within the driving experience, participants proposed several innovative ways to enhance interaction with others. One set of ideas focused on communication and sharing experiences. This included making calls with family and friends and virtually exploring the open road together by sharing travel experiences. Participants also suggested playing games with other drivers during traffic jams.

   Another aspect of socialization involved sharing information and engaging with others in a more visible way. The concept of using a small LED sign outside the car to announce significant life events, such as "Just Married," was discussed. Additionally, ideas included using cool exterior lights or displays to attract pedestrians and facilitate direct interaction. The notion of sharing stats between cars, similar to social workout apps like Strava, was also proposed. This could allow drivers to share information about race tracks or other metrics, as well as receive notifications from fellow drivers about hazards or obstacles to avoid.

3. **Car as a space for stimulation**: To inject excitement into the driving experience, ideas included integrating karaoke for in-car entertainment and gamification elements to challenge drivers and reward their achievements. Participants suggested incorporating features for learning new skills while driving and creating dynamic lighting effects synchronized with music. The concept of experiencing new and unique sights, such as discovering a new restaurant

or observing ongoing events, was also highlighted.

3.2.2.3 Concept Screening

To effectively screen the concepts, I evaluated them against several key criteria as follows:

1. **Alignment with Goals and Objectives**: The primary aim of this project is to enhance the commuting experience, making it more enjoyable and pleasant. Concepts should align with this objective.

2. **Polestar Essence**: Ideas should embody the essence of Polestar, seamlessly integrating into the brand's car experience. It is important to consider how easily each concept can be incorporated into the existing Polestar car design with minimal modifications.

3. **Design Space**: Evaluate the potential for further design development. The concept should allow additional design improvements and refinements in this project.

4. **Innovation and Uniqueness**: The concept should offer something innovative and unique, setting it apart from existing solutions.

5. **Potential Impact**: Assess the potential impact of the concept on users, including its ability to enhance their commuting experience and overall well-being.

I sorted the results from two workshops thematically in the affinity diagram above. The most viable directions were as follows:

1. **Car as a space for socialisation**: Shared Experience with Others.

    (a) Facilitate conversations through intellectual engagement and shared interactions with landmarks displayed on the windshield.

    (b) Create collaborative artifacts, whether digital or physical. For example, occupants could work together on music creation or artistic projects such as painting.

    (c) Enable interaction with strangers during traffic jams by playing games with nearby vehicles or sharing information. This feature fosters a sense of community and entertainment while waiting.

    (d) Enhance family time by providing opportunities for video calls and collaborative games.

    (e) Enhance Reinforce the group togetherness, providing an experience of being in one group even in separate vehicles.

2. **Car as a space for transition**: Implement mood detection systems to monitor and regulate the driver's emotional state. This can trigger customized relaxation features based on real-time emotional feedback. For instance, I can create a calming in-car environment by adjusting lighting, playing mood-enhancing audio-visual clips, and diffusing soothing scents. This approach aims to reduce stress and improve overall well-being during the commute.

Polestar is a driver-centered brand that prioritizes the driving experience. Given that the typical number of commuters is 1.2 people, indicating that individuals usually drive alone, the concept of co-experience among occupants becomes less relevant. Additionally, commuting routes are often mundane and repetitive, especially in city centers where speeding for stimulation is not an option. Finding new sources of excitement, new actives or restaurants, along the route is also challenging. Lastly, considering safety and legality, participating in family activities while on commuting could be distracting, even with Level 3 autonomous driving capabilities in Polestar vehicles.

Research indicates that commuters typically use their commute as a transition period to prepare for upcoming activities. In the morning, they often use this time to organize their agenda, review their calendar, and mentally prepare for the workday. Conversely, on the return journey, they might seek relaxation or look for evening social events. Focusing on relaxation during the commute is a viable and promising approach. Polestar 4 already includes numerous built-in sensors, such as cameras and ambient lights, which can be leveraged without significant additional investment. Enhancing the commuting experience by reducing stress and improving overall well-being aligns well with Polestar's luxury brand essence. This area is relatively under explored in the autonomous vehicle industry, which presents a large space for future innovative design.

In summary, the final design direction for this project will focus on enhancing therapeutic relaxation during the commute. The concept will be further elaborated on in the upcoming chapter, called "Commuting Therapy".

3.2.3 Evaluation

I performed a Virtual Reality (VR) simulator study with 11 participants to explore user perceptions of *Commuting Therapy.* The primary objective of this study was to assess current multisensory, emotion-based experiences within the context of automotive design and to provide recommendations for enhancing future experience design. To achieve this, I examined various promising emotion regulation strategies (different sensations) under the affective interaction within the car environment and analyzed their impact on user experience and driving performance. my investigation focused on how these multisensory strategies could be integrated into the design to improve overall commuting satisfaction and safety.

3.2.3.1 Study Design

Numerous studies have shown that the different sensory strategies incorporated in the *communication therapy* positively affect the regulating driver states [4] [22] [40] [41] [39]. However, I remain uncertain about the rationality of combining various sensory inputs within the driving context of commute and how well this concept aligns with the identity of the Polestar brand. This user study was designed with the objective of collecting perceptions of different affective strategies in drivers during commutes. As independent variables, participants experienced the four strategies introduced above plus a demo video of the interface without direct interaction.

I collected dependent measures on the driver's emotional state, as well as subjective feedback on overall experience. The experiences under four strategies was assessed by PrEmo and the overall experience was assessed by user experience questionnaires after the VR stimulator experience. Before and after every concept interaction, participants were explained how to use different assessment instruments and how different strategies will look like in future scenarios. The study is not to examine effectiveness of the *Commuting Therapy* to regulate the emotional states. Thus, Physiological sensors on the steer wheel provided data streams on heart rate and skin conductance level, and a driver camera allowed the analysis of emotional states from facial expressions were not used in this study.

The study was structured according to Jordan's four product pleasures framework, all information was collected under ideological pleasure, sociological pleasure, physiological pleasure, and psychological pleasure. Psychological pleasure is the focus of this study where I used the Product Emotion Measure (PrEmos) [75] to help subjects express their emotions under four strategies. This method requires the participant to think of and write down an experience from their past which had elicited positive or negative emotion, picking an animation that matched the mood and elaborated the reason behind. To recall this emotion while driving, participants told the story aloud with me in a setting that protects their privacy. Information about the other three pleasures was collected during the later short interview.

In the end, participants were interviewed using a semi-structured approach, focusing on Jordan's four dimensions of product pleasure. They shared their feelings and experiences related to each strategy and their overall impressions.

3.2.3.2 Participants

11 participants aged 25 to 64 years participated in the study. After discarding one dataset due to missing measures, I take into account n = 10 (5 male, 5 female). Most of the participants were extremely frequent car users and extremely into the technology. In addition, all of them had never previously interacted with a system that considered their emotional state.

3.2.3.3 Methods

The methods I used to collect data are Product Emotion Measure (PrEmo), User Experience Questionnaire (UEQ) and Semi-structured interview.

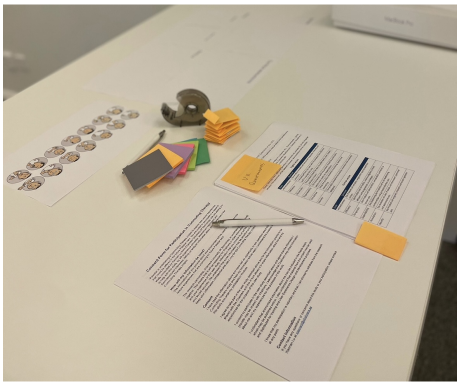

Figure 3.3: Measure instruments

Understanding human emotions is crucial to gain insight into their mindset, preferences, and behavior. However, people often struggle to articulate their inner feelings accurately. PrEmo is specifically designed to address this challenge by making emotions measurable. It is a non-verbal self-report instrument that features 18 distinct product-related emotions, visualized through animations of a cartoon character [75]. Participants can convey their emotions by selecting the animations that best match their feelings. In the study, I utilized an online version of PrEmo [1], which showcases a hand-drawn character (either male or female) expressing 14 different emotions—seven positive and seven negative—through various actions (see Figure 3.4). These 14 emotions provide a comprehensive representation of the human emotional spectrum [1]. The emotions involved are joy, hope, pride, admiration, satisfaction, fascination, desire, sadness, fear, contempt, dissatisfaction, boredom, disgust.

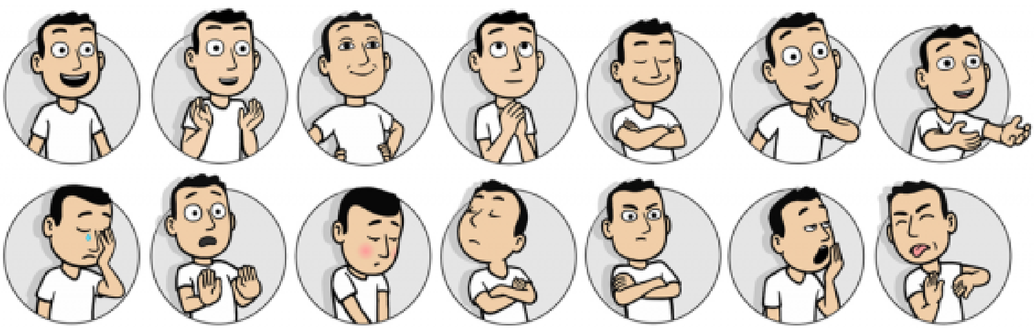

Figure 3.4: Product Emotion Measure [1]

I divided the whole experience into four sensations that were involved: Vision, sound, smell, and tactile sensations. Additionally, the vision is consist of nebula animation and ambient light. Participants were encouraged to select multiple emotion animations under one sensation, provided they experienced those emotions and could explain their choices.

Another measurement instrument is User experience questionnaire (UEQ). UEQ [142] is an end-user questionnaire to measure user experience quickly in a simple and immediate way while covering a preferably comprehensive impression of the product user experience. It was used to measure the user experience of software products in several empirical studies. Data were subjected to a factor analysis which resulted in the construction of a 26 item questionnaire including the six factors Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation, and Novelty. Studies conducted for the original German questionnaire and an English version indicate a satisfactory level of reliability and construct validity.

Participants were asked to complete the UEQ following the discrete emotional evaluation across four different sensations. The overall experience was then assessed using both the UEQ and subsequent semi-structured interviews.

Lastly, semi-structured interviews were conducted to gain qualitative insights into participants' experiences with the *Commuting Therapy* system. These interviews focused on exploring the four product pleasures [140] and the overall user experience: Ideo-pleasure, Socio-pleasure, Physio-pleasure and Psych-Pleasure. For specific questions, please refer to Appendix 1.

Figure 3.5: Basic setup

3.2.3.4 Apparatus

The study was carried out on a high-fidelity driving simulator at the Polestar Design VR Studio. Figure 3.5 shows the basic setup, consisting of a fixed-base Polestar 2 mock-up seat, a steering wheel, a physical center screen, a VR headset and a screen on the wall. The simulation of the experience was presented by the Polestar visualisation team. The visual components of the concepts were presented on a Microsoft Surface tablet located in the original position of the central information display in the VR environment, with Nebula animation and lighting divider. VR Landscape changes along with the two different pre-set emotion modes in commuting therapy. Ambient light was achieved within the VR environment, without realizing dynamic lighting as stated in the concept. The auditory parts were played through the VR headset speaker system. The seats in the test were not fully functional, only being able to adjust the seat fore and aft as well as the angle, and not massaging it. So for the haptic part, I verbalized exactly what scenarios it would be turned on and used in, and how it would not affect safety. Finally, to simulate the in-car aroma experience, I discreetly applied different perfumes to my arms and subtly moved closer to the participants during the VR simulator session.

In the open space where the experiment took place, the simulation area and control station were divided by separate operation desks. Due to technical challenges, I manually managed the transition between the two pre-set emotion modes. The screen mounted on the wall behind the simulation area mirrored what the participants saw in their VR headsets (See Figure 3.6). To ensure a seamless experience, I synchronized the video, audio, and landscapes with the participants' progress in the VR simulation, making real-time adjustments as needed.

Figure 3.6: VR scene on screen

3.2.3.5 Procedure

At the beginning of the experiment, I introduced the project background, goals, and the expectations from this study. I also explained my intention to assess the concept based on participants' experiences. The participants were then invited to sign a consent form. The core of this user study was presented through an app demo video displayed on a central screen within a VR environment, although there was much more behind the scenes. Initially, I explain the operation of the emotion-based interactive car system before launching the app. This helps participants better understand the concept and addresses any limitations in the presentation of the test equipment.

I introduced what happens before opening the APP as follows:

Many studies have proved that different colors and intensities of light create different psychological feelings, and light can also affect the body's biological clock, particularly by regulating melatonin production. Blue light, for example, suppresses the production of melatonin, making people feel more awake and alert. When you are seated in the car, the car system starts reading your emotional states through facial expression analysis and hand-wheel sensors. After assessing your emotional valence and arousal, the car system will recommend a corresponding mode to regulate your emotional state through different sensations. It is up to you whether you use this mode or change to another mode. What is noticeable during the VR experience is that all the sensory settings in the real situation will be configured in advance. Due to some technical problems, the resolution on the screen is not super clear.

The participants were then invited to sit in the car seat and put on the VR headset. They had a few minutes to explore the virtual environment and adjust the car seats for maximum comfort. Once they were ready, the main VR experience began, lasting about five minutes. During this time, they engaged in a multisensory experience that included visuals, sounds, smells, and tactile sensations. Participants were encouraged to imagine that all the functions they encountered in VR were autonomously occurring around them during their daily commute. After the VR session, participants had the opportunity to ask questions to deepen their understanding of the concept. Following this, they completed a psychological evaluation using PrEmo and a user experience questionnaire based on their experience. Participants were asked to evaluate strategies according to their personal perceptions and justify their decisions in a short, unstructured interview, where the conversation was recorded.

3.2.3.6 Limitations

The study was conducted in a VR simulator due to practical and safety concerns. I expect the results to be comparable to those in a real driving context. Participants were employees of Polestar; however, I exercised due care in recruiting to avoid a biased user sample.

4

Concept: Commuting Therapy

The *Commuting Therapy* concept aims to transform the daily commute into a pleasant and healing experience by integrating visual, auditory, olfactory and tactile elements. This emotion-based interaction design is tailored to improve the physical and psychological well-being of drivers, leveraging multisensory stimulation to create an adaptive environment that mitigates the negative emotions during the commute.

4.1 Driver Emotion detection in Polestar

An effective in-car system must, first and foremost, be aware of the driver's state. Based on the literature review and the existing technologies in the Polestar cabin, the detection methods that commuting therapy will employ cover all three fields: physiological measurements, behavioral measurements, and self-reported scales.

Noticeabllyblly, Li at al. [22] stated that the driver's facial expression may be suppressed due to the influence of the driving task, because driving is a complicated cognitive process, which is related to driver's age, gender and driving experience. What else? Many researchers found that facial expressions of emotions are not culturally universal [143] [144]. This is why I need physical sensors in commuting therapy. Physical sensors in general allow one to collect unbiased and fine-grained emotional information without adding additional workload to users, which is critical when driving a car [89].

The preferred detection methods are non-invasive to ensure drivers do not feel constantly monitored and distracted. All in all, the emotion detection system in Polestar is a multi-resources system. The specific methods used in commuting therapy include:

- **Physiological Measurements:** Capturing and analyzing heart rate, skin conductance level, and skin temperature through sensors on the steering wheel.
- **Behavioral Measurements:** Using in-car cameras to observe facial expressions, incorporating user information such as age, gender, driving experience, and cultural background to facilitate the deduction from the facial expressions.

Furthermore, the driving style, posture in sitting, and motion need to be taken into consideration as well.

- **Driving context factors:** Environmental factors (roads, weather), situational factors (traffic), and interpersonal factors (conversations, user interfaces) and thus fluctuates the driver emotional states continuously.

- **Self-Reported Scales:** Gathering feedback from drivers after each experience, especially during the initial phase of the commuting therapy. The self-reported data will be integrated into a machine learning process, enhancing the accuracy and customization of emotion detection in future experiences.

In summary, *Commuting Therapy* will leverage dimensional emotion theory [58] as the foundation for in-car emotion detection, focusing on two key psychological dimensions: valence and arousal. Future Polestar vehicles could integrate sensors into the steering wheel to monitor physiological signals such as heart rate, skin conductance, and skin temperature, which indicate emotional arousal [75] [79] [80] [81]. Additionally, *Commuting Therapy* will utilize the built-in cameras to analyze facial expressions, which reliably reflect the valence of an individual's emotional state [60]. The system will also account for variables such as age, gender, driving experience, and cultural background, as these factors influence facial expression. Additionally, the driving style, posture in sitting, and motion will be taken into consideration as well. There is a strong correlation between body gestures and driving behaviors. The steering wheel angle and gas pedal angle can reflect the drivers' body gestures, which can be used to deduce the body gesture [53]. Furthermore, factors in the driving context, such as environmental conditions, situational dynamics, and interpersonal interactions, will be considered to achieve a more accurate assessment of driver emotions. Finally, self-reported scales will be incorporated to enhance the precision and personalization of emotion detection in the *Commuting Therapy*.

4.2 Driver Emotion Regulation in Polestar

In context aware systems research, one of the definitions of context-aware computing is the ability of a mobile user application to discover and react to changes in the environment (i.e., driver mood state) in which they are situated [145]. Context is defined by different concepts or factors such as time and/or date, weather conditions and user's emotional state.

4.2.1 Desired emotional state

The objective of commuting therapy is to keep the driver in a desired state of mood by providing different stimulus to regulate users' states, contributing to flourish well-being after commuting. Regulative efforts should take place when the current driver's mood is not desirable.

The difference between "emotion" and "mood" is that the mood describes longer period of states. So, the car detection system is based on constantly changing emotions, and the goal is a relatively long state.

In the driving context, medium activation is seen as an optimal level of arousal [3], and positive valence is generally desired as a sign of a good user experience [42] (see Figure4.1). Braun et al. [42] stated that the state where drivers are in medium arousal and high valence has the least negative effect on driving, in other words, safe driving.

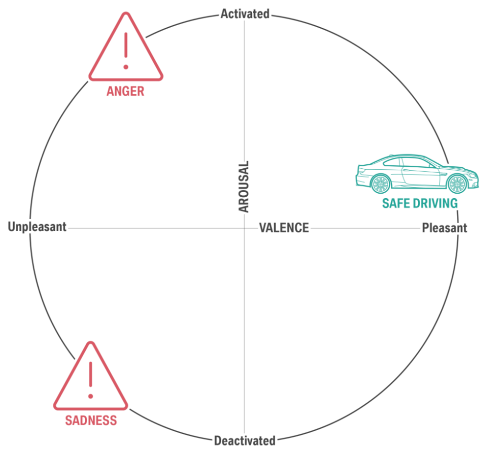

Figure 4.1: Driver state taxonomy based on Russel's circumplex arousal-valance model [2] and the Yerkes-Dodson law [3]. Positive valance and medium arousal values have been shown to be the desired states in driving [4]

4.2.2 Affective state regulation modes

In this commuting therapy project, the goal is to achieve the desired driver state, as illustrated in Figure 4.1, helping to improve their well-being. The affective state regulation system consists of two modes:

1. **Mood Regulation**: The target state (medium arousal, high valence), different from the current state, is set as the goal.

2. **Mood Maintenance**: The driver is already in a suitable state, so actions are taken to maintain it.

4.3 Emotion-based multi-sensory interaction

4.3.1 Visual stimuli

Vision is the dominant sense during driving, which is why most emotion regulation is based on visual stimuli. Studies conducted by Siedlecka and Denson [88] have shown that visual stimuli generally achieve better results in emotional induction for basic emotions. For low levels of automation, using visual stimuli for driver emotion regulation may cause potential distractions. However, the need for visual regulation can be relaxed when the vehicle operates at a high level of automation. In this project, the automated level of future Polestar cars is set between levels 3 and 4, meaning that visual stimulation can be applied in certain scenarios, such as traffic jams or slow-moving traffic, without compromising safety.

Polestar, with its "star" name and unique star-shaped logo on every generation of cars, has a strong connection to the cosmic theme. For instance, the Polestar 4 uses the narrative of the solar system in its ambient light settings, offering nine ambient light color choices corresponding to the nine planets. Different auto manufacturers often highlight unique narratives behind their functionalities, which is crucial to marketing success. I aimed to find a story that suits commuting therapy and integrates seamlessly into the Polestar brand.

There are many stories that I could tell, ranging from the Galaxy, eclipse to numerous nebulae in cosmic space. Nebulae, with their vibrant colors and diverse shapes, resonate with the intention of using different colors to subconsciously regulate users' emotional states. The colors of nebulae are primarily influenced by the composition, temperature, and density of the gas within them, as well as by surrounding light radiation, dust scattering, and other factors. The colors of nebulae are indeed variable and are influenced by observational conditions and environmental factors. However, they often exhibit characteristic colors in the spectrum at different wavelengths, manifesting consistently under certain conditions.

4.3.1.1 Ambient light

Ambient light refers to the use of ambient illumination in the cockpit to regulate driver emotions [53]. Contrary to conventional concerns that lights can distract drivers, some researchers claim that in-car lights can assist drivers [131].

This project will continue using the existing in-car lighting system to minimize costs. Based on the literature review, the commuting therapy will adopt the emotion induction methods proposed in the color psychology field [126] [127] [128]. This system primarily uses the brightness and saturation of light colors to regulate emotions (valence, arousal, and dominance). For instance, brighter and more saturated colors will be used to increase pleasure (valence), while more saturated and less bright colors will generally be used to increase arousal.

The commuting therapy will prioritize colors like blue, blue-green, green, red-purple, and purple, as they elicit higher pleasure levels compared to green-yellow, yellow, and yellow-red. Green hues (green-yellow, blue-green, and green) will be used to increase arousal, as they typically elicit the highest arousal reactions. For example, the arousal level for green-yellow was significantly greater than for purple-blue, yellow-red, and red-purple.

Artists and designers often distinguish "warm" (high saturation, low brightness) from "cool" (low saturation, high brightness) colors, assuming that warmer colors induce greater activity [146]. Mehrabian and Russell [147] reviewed findings showing that judgments of color warmth were highly reliable, supporting the use of two modes in commuting therapy: awakening in the morning and destressing in the afternoon.

Recent studies show that 1 hour of exposure to bright blue-enriched white light in the morning advances sleep and wake-up parameters, and also improves cognitive performance and alertness [115]. Conversely, warm light exposure in the afternoon induces calm and relaxed moods [148]. Based on these findings and the general needs of commuting scenarios, the commuting therapy proposes two modes: an awakening mode in the morning and a destressing mode in the afternoon, which will be further explored in later user studies.

4.3.1.2 Nebula animation

Based on different driver states, different nebulae animation will be presented on the center information display. A dynamic moving nebula animation is displayed on the screen, showcasing detailed and breathtaking views of nebulae. The real ambient light matches the changing colors of the nebula, with fading or blinking effects that resonate with the music features described below. The nebula animation on the screen also vibrates and changes shapes in sync with the music rhythm.

Due to the increasing use of the cluster display type, lighting design is not limited to the ambient light in the car. In a broader sense, lighting designs must incorporate the light effects caused by the luminous surface of the cluster display as well [40]. As shown in Fig. 4.2, dynamic nebula animations are displayed in the background, overlaid by a highly illuminated lightning square. A rigid cutting line divides the animation on the screen, extending the ambient light into the smart cabin. This cutting line is aligned with the real light strips in the car, ensuring a consistent visual experience.

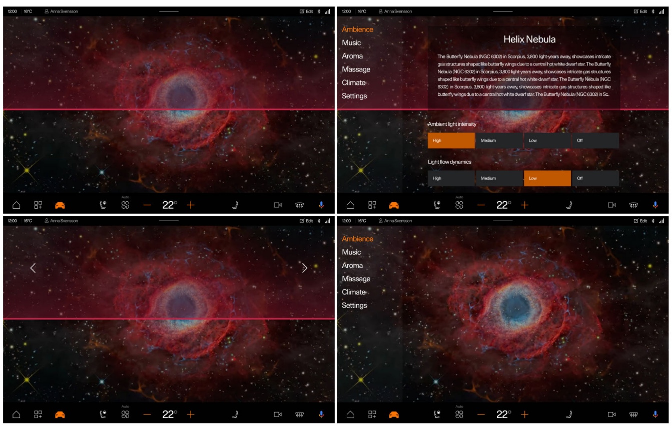

Figure 4.2: Nebula animation high fidelity prototypes

Based on color preference research [127] [128], visual stimuli for commuting therapy, such as Nebula-themed dynamic ambient lights and screen animations, will use colors including blue, green, purple, violet, red, orange, and yellow. Examples of corresponding nebulae include the Blue Horsehead Nebula, the Green Orion Nebula, the Purple Lobster Nebula, the Violet Helix Nebula, the Red Eagle Nebula, the Orange Flame Nebula, and the Yellow Crab Nebula and so on.

4.3.1.3 State feedback

State feedback refers to the visual display that allows drivers to clearly understand their current emotional states [53]. The question of how and whether detected states should be displayed has been crucial in the field of driver state detection [93]. Studies have found that direct feedback on the detected driver's states has little value for emotional regulation, as visual state feedback can amplify the driver's negative emotional states, which is generally unacceptable and needs to be avoided [92] [93] [4]. However, drivers generally seem open to continuous driver state displays, provided the criticality of the situation is easily discernible [149] [93]. Furthermore, Braun et al. [93] found that driver age, experience, and personality traits significantly impact the user experience of driver state visualization. While a continuous display is generally preferred, older respondents and inexperienced drivers favored systems with fewer visual elements. Furthermore, extroverted participants were more open to visual interventions [93].

The Commuting Therapy system provides only safety-critical notifications of the driver's state through the graphical UI on the center information display and dynamic ambient light. It monitors four potentially safety-critical states: drowsiness, aggressiveness, high workload, and hypoglycaemia, and includes one-time warnings to alert the driver to immediate safety risks [149]. The default setting for the state feedback display will be adapted to the driver's age, driving experience, and personality [93], and the information display system is adjustable according to user preferences.

Based on the literature review on dynamic lighting patterns [124], the dynamic ambient lights will use discrete blinking lights for urgent notifications, as they cause the highest level of alertness. For music-resonating vibes, smooth blinking or spread patterns will be employed, as they are less intrusive and more energizing.

4.3.2 Adaptive music

Since the advent of the first car radios, listening to music has been one of the favorite activities for people while driving, with about 70% of drivers doing so [95]. Driven by their tastes, attitudes, moods and the nature of their trips, people have always selected the most suitable songs from their libraries, creating their own customized playlists. Research indicates that positive emotional reinforcement occurs when individuals engage with preferred and familiar music, as well as during activities such as singing and improvisation. Conversely, elements such as complexity, dissonance, and unexpected sounds typically have a negative impact on the emotional state[97].

Commuting therapy adopts and refines the mood-based on-car music recommendation systems proposed by Çano et al.[97], which stated that the dimensions of the music recommendation based on mood could be defined as:

- **User** $\subseteq$ Uer name $\times$ Age $\times$ Profession
- **Item** $\subseteq$ Song Title $\times$ Artist $\times$ Genre $\times$ Mood Label
- **Context** $\subseteq$ Time $\times$ Location
- **Mood** $\subseteq$ Driving Style $\times$ Facial Expressions $\times$ Heart Rate

The formula above has been revised to better align with the specific requirements and conditions of the project. The music mood recommendation is embedded in many music social communities, such as Spotify, Last.fm, or TIMmusic. The recommendation system uses various sources of information for tuning the recommendations: physiological information from the in car emotion judgement system; user's saved musical preferences to take into account his/her musical tastes; telemetry of the current drive to consider the actual driving style of the user; location and time information to adapt the chosen playlists to the driving context.

However, the perception of music and accompanying emotions is highly subjective. Thus, one piece of music can hardly be classified into a category of emotions it will induce. As a solution to this uncertainty problem, approaches have emerged to annotate music titles with crowd-sourced values of arousal and valence, such as the DEAM Database for Emotional Analysis in Music [101]. Researchers are increasingly relying on such databases [101] [150] instead of subjectively selected music to recommend music.

Commuting therapy uses the two values (arousal and valence) provided by the in-car detection system to identify the mood category the driver is in. As shown in Fig. 4.3, the system can recommend songs from either the user's favorite list or from a larger database to regulate users' states. Noticeably, when the user is already in the desired mood, the recommendation system gives more priority to his/her past musical preferences.

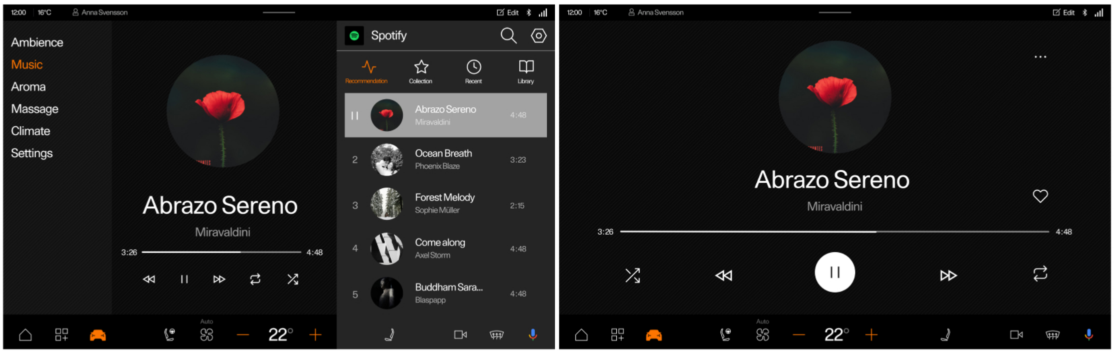

Figure 4.3: Adaptive music high fidelity prototypes

4.3.3 Aroma

Olfactory displays are gradually entering the field of automotive human-machine interface (HMI) as a novel method of human-vehicle interaction. In the Commuting Therapy system, I offer various emotion regulation modes, prominently featuring four main modes: Destress, Awakening, Calm, and Rejuvenate. These modes are accessible in the app interface, allowing users to select and prioritize their preferred modes. Additional modes can be found under "More" and can be pinned to the top bar for easy access. Users have the flexibility to stop and restart the scent diffuser, switch between different types of aromas, and view information such as diffusion time and scent types directly on the screen.

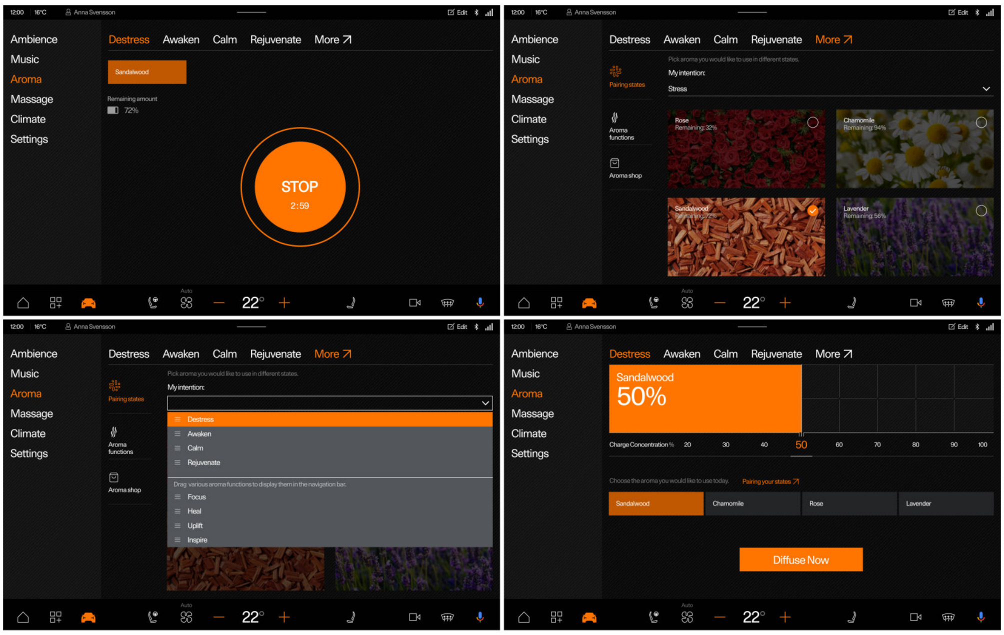

Figure 4.4: Aroma high fidelity prototypes

According to previous research, different aromas have distinct functionalities and are associated with varying levels of valence and arousal. Commuting Therapy provides default aroma recommendations based on this research and offers detailed descriptions of each aroma's effects. For example, aromas such as vanilla and lavender are known to induce positive emotions and promote relaxation, resulting in a more comfortable and fresh feeling[105]. Similarly, rose and peppermint can shift drivers' emotions towards a positive valence[106]. Aromas like peppermint and cinnamon are effective in reducing driver frustration and enhancing alertness and focus [104].

It is essential to note that olfactory responses can be subjective and vary between individuals. Therefore, Commuting Therapy adopts a personalized approach to aroma regulation, allowing drivers to pair different aromas with their emotional states. For example, if users frequently feel drowsy in the morning and find that orange scent is the most effective in keeping them alert, they can pair this aroma with the Awakening mode.

I envision that users will be able to purchase the electronic scent diffuser and refillable scent capsules from the Polestar accessory store. Each aroma is produced in a capsule form, and customers will receive notifications when their aroma is running low, enabling them to conveniently order refills from the online store.

4.3.4 Haptic Stimuli

Massage seats are common in vehicles, with some manufacturers offering various massage settings. This project focuses primarily on force and temperature, with additional consideration for airstreams and vibration.

4.3.4.1 Force

Given that future Polestar cars will feature Level 4 autonomous driving, allowing full control to be handed over to the vehicle, the massage seat will be automatically activated during traffic jams. This feature provides physical comfort and helps relieve driver stress.

4.3.4.2 Temperature and Airstreams

Temperature control has been shown to mitigate effects of high arousal. Effective temperature control can create a comfortable and calming environment in the vehicle, enhancing overall user satisfaction [53]. Temperature control has been shown to mitigate effects of high arousal [107] [108]. As part of the Commuting Therapy system, heated or cooled seats provide physical comfort, helping drivers manage stress levels. Additionally, cool airstreams play a crucial role in maintaining driver alertness. Schmidt et al. [76] found that cool airstreams can decrease low arousal and increase alertness and sympathetic activity, leading to improved driving performance and acceptance. Consequently, when the car detects that the driver's alertness is low, gentle cool airstreams will be activated to help increase their awareness and ensure safer driving conditions.

There is an interesting association between temperature and color. A study conducted in a light laboratory found that room temperature was perceived differently depending on the color of the lighting. Specifically, in yellow light, the room temperature felt warmer than in blue light [109]. This insight will be incorporated into the temperature settings as well. For instance, when drivers get into their cars on a cold and dark evening after work, the system will turn on warm lighting to provide a cozier feeling.

4.3.4.3 Vibration

Vibration can be an effective way to provide physical feedback to drivers. A study by Dass et al. [16] found that haptic warning signals are as effective as audible ones in maintaining driver attention. In the Commuting Therapy system, steering wheel or seat vibrations are used to keep drivers alert and manage stress levels when faced with safety threats. This physical feedback mechanism ensures that drivers remain focused, thereby enhancing overall safety and comfort during their commute.

5

Results

I structured and analyzed my user study using Jordan's four product pleasure framework [140], which categorizes experiences into Ideo-pleasure, Psycho-pleasure, Physio-pleasure, and Socio-pleasure. The results are presented according to the different sensations involved in the experiences, primarily assessed using PrEmo, focusing on psycho-pleasure. The overall experience was evaluated through the UEQ, which encompasses all four pleasure categories. Semi-structured interviews were conducted both during the process to explore the reasons behind emotional reactions and after the UEQ to gather insights on the general experience. The information collected from these interviews is integrated into the relevant subsections.

The results from this user study manifest the importance of a multisensory approach in designing emotion-based leisure experience during commutes. All the sensations, visual, olfactory, auditory and tactile stimuli, contribute to the overall experience, each playing a unique role in shaping user perception and emotional response. Personalisation and user control emerged as key themes across all sensory domains, highlighting the need for flexible, adaptive systems that can cater to individual preferences and needs.

5.1 Emotional assessment under different sensations

Since PrEmo is designed to be intuitive, it is generally recommended not to provide detailed explanations of each emotion's meaning during user testing [75]. The tool allows participants to naturally select the animations that resonate with their feelings, free from the influence of predefined labels or definitions. Participants were encouraged to choose multiple emotion animations under a single sensation or to leave the sensations blank if they did not evoke strong emotions.

In practice, all participants interpreted one animation as representing curiosity instead of fascination, and another as sleepiness instead of boredom. Consequently, I used curiosity and sleepiness to measure the results. Reactions to the different sensations were notably influenced by participants' personal preferences, particularly regarding the specific stimuli provided in the study, such as scents and music genres. These individual sensitivities had an impact on the results, with 11 of the 14 available emotion types being used.

Figure 5.1: The emotional assessment of different sensations

5.1.1 Auditory stimuli: Adaptive music

Participants generally found the integration of adaptive music with the car system to be beneficial, noting its positive impact on mood and the driving experience. The most frequently reported emotional reactions to the music were *Satisfaction*, *Desire*, and *Joy*, followed by *Admiration* and *Pride*. However, one participant expressed *Fear* due to the volume of the music, while another reported *Sleepiness* because the music type did not match their preferences.

5.1.1.1 Positive feedback

Participants appreciated the idea of matching familiar songs from favorite song list with (desired) emotional states, finding it useful as it reduces the need for manual effort. There was also strong enthusiasm for discovering new music through recommendations, with excitement about how music could positively influence emotional states and driving performance.

Several participants agreed that music has a significant impact on mood and is effective for mood regulation. The adaptive music feature, paired with animations, was considered a *Cool* addition, and the idea of mood-matching music recommendations was well-received.

5.1.1.2 Suggestions and Preferences

While the adaptive music feature was praised, there were suggestions for more personalized control, additional audio book content or local radio options, and integration with external apps to further enrich the experience.

The music during the test was generally well-received, with participants feeling it had the right amount of energy without being overwhelming. One participant desired more control over music volume, with a preference for the system to automatically adjust sound levels according to individual preferences. There was also a call for an efficient and automatic playlist management system. Another participant highlighted the value of music in masking road noise, which should be considered when developing the automatic sound system.

Two male participants aged 45-64 suggested alternative audio options, such as audio books or local radio. They suggested that if the system can be integrated with music apps like Spotify, it could also support more other third-party apps, enabling access to a wider variety of audio content. These preferences for varied audio content should be taken into account when designing for this age group. The *Commuting Therapy* system could potentially collaborate with more apps to offer customers a wider array of choices.

5.1.2 Visual stimuli: Nebula Animation

The Nebula animation received the highest amount of negative feedback compared to other sensations. On the negative side, the most frequently mentioned emotions were *Fear* and *Contempt*, followed by *Sleepiness* and *Disgust*. On the positive side, the most commonly reported reaction was *Curiosity*, with *Hope* and *Joy* also noted.

5.1.2.1 Divergent Attitudes

Among the participants, 3 out of 10 expressed a strongly negative attitude towards the animation. One participant mentioned not wanting *Strange things* happening on the screen, while another noted that the animation made him want to yawn. A third participant raised significant concerns about driving safety, stating that the animation would likely be more of an annoyance than a benefit. Even when the concept of a "gaze wake-up screen" was proposed—where the screen would only activate when the driver gazes at it, such as during a traffic jam—this participant suggested that a completely black screen to force drivers not to watch might be more beneficial. They argued that a black screen would encourage a *daydreaming* immersive experience, potentially enhancing well-being while also addressing safety concerns.

Another 3 participants exhibited a more conservative stance, voicing concerns about potential distractions and questioning the effectiveness of animations on small screens compared to ambient lighting. One of them advocated for a customizable option to turn off the animation if it proved undesirable.

In contrast, one participant expressed a highly positive attitude towards the animation, while three others had moderately positive views, describing it as *cool*, *mesmerizing*, and *easy-going*.

Although some participants found the nebula animation to be easy-going and mesmerizing, others perceived it as less engaging on the small screen, and even overwhelmingly distracted. This variation in responses underscores the need for customizable options that allow users to personalize their visual experience, thereby accommodating a broader range of preferences.

5.1.2.2 Suggestions and Preferences

One participant suggested to have the autonomy to select nebulae and pair different nebula types with various emotional states. Additionally, three participants suggested specific types of animations they would like to see: more abstract visuals such as underwater wildlife and rainforests, relaxing animations like galaxies, space, and waves of water, and animations with soft colors and movements. Lastly, the animation feature should offer customization options, allowing users to adjust or toggle the animations according to their preferences.

5.1.3 Visual stimuli: Ambient lights

Participants generally expressed a positive attitude towards the ambient lights, with the most frequently mentioned emotional reactions being *Joy*. Following these, *Desire*, *Satisfaction*, *Hope*, and *Admiration* were also noted. Only one participant expressed *Contempt*, primarily due to a general resistance to visual stimuli while driving.

5.1.3.1 Divergent Attitudes

Six participants had strongly positive attitudes towards ambient lighting, noting its effective impact on enhancing the overall experience and making the car feel more personalized as a space. They described the lighting as *relaxing* and *desirable*, with one participant observing that their energy levels seemed to shift along with the changing ambient light. Another participant appreciated dynamic lighting that adjusts with the music.

Two participants expressed satisfaction with the static lighting in the VR simulator, indicating that they were content with the luminance function and did not want additional features.

Conversely, two participants raised concerns about the potential for ambient light to be distracting and induce sleepiness, especially at night. One noted that the lights were more attention-grabbing inside the cabin, potentially diverting focus from the road, while another participant felt that the ambient lights had minimal impact, contributing instead to a sense of drowsiness.

5.1.3.2 Suggestions and Preferences

There were affirmations for dynamic features in which the lights could change in sync with the music to enhance the experience. Another participant suggested having a luminance-only function without additional lighting effects. Some participants did not like ambient lights. Preferences varied, with some liking the current setup and others suggesting further customization options to tailor the lighting to individual tastes and needs.

5.1.4 Olfactory stimuli: Aroma

All participants generally viewed in-car scents positively, with the exception of one who expressed *Fear* and *Disgust* due to a mismatch between the provided aromas and their personal preferences. However, this participant clarified that despite their negative experience during the study, they considered the feature to be a valuable addition. Given the novelty of this feature, many participants had never encountered it before. As a result, the most frequently mentioned emotion was *Curiosity*, followed by *Hope*, *Admiration*, *Satisfaction*, and *Joy*.

5.1.4.1 Positive feedback

Several participants expressed positive reactions towards the in-car scent feature, believing that in-car scents have a significant influence on mood. One participant noted that scents could have a considerable subconscious impact, akin to their use in retail, and could greatly affect mood. Some participants, who had never encountered this feature before, described it as *cool*, *innovative*, and *awesome*, recognizing its potential value. Participants noted that pleasant scents, such as those mimicking natural environments (e.g., pine forests or ocean breezes), contributed to a more positive and relaxing atmosphere.

5.1.4.2 Suggestions and Preferences

Two participants, both frequent users of scents in their daily lives, suggested the option to customize their own car scents. Another participant proposed that Polestar can develop signature scents to convey a sense of luxury and brand identity.

5.1.5 Tactile stimuli: Temperature, Massage and Air stream

Participants were generally familiar with the tactile sensations, including temperature and massage, and expressed a positive attitude toward them. The most frequently mentioned emotion was *Satisfaction*, followed by *Joy*, *Pride*, *Hope*, *Desire*, *Curiosity*, and *Admiration*. Despite the overall positive feedback, three participants expressed concerns about distraction and drowsiness, mentioning *Fear*, *Sleepiness*, and *Disgust* when the massage intensity was too strong or the temperature was too warm.

5.1.5.1 Positive feedback

Participants generally had positive reactions to the tactile sensations in the car, particularly the massage function. They found it relaxing and stress-relieving, with some noting that it enhanced the car's comfort, making it feel more like a home environment, akin to a sofa or comfortable chair. The massage feature was specifically appreciated for its potential benefits during long commutes.

5.1.5.2 Suggestions and Preferences

Some participants expressed concerns about the potential for tactile sensations, particularly the massage function, to be distracting or overly relaxing. They suggested that such features should be carefully designed to avoid affecting driving performance or inducing sleepiness.

5.2 Overall experience assessment

The User Experience Questionnaire (UEQ) comprises 26 items grouped under six factors: Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation, and Novelty [142]. *Attractiveness* refers to how visually appealing, pleasant, and friendly the product appears. *Efficiency* assesses the ease and speed with which users can complete tasks using the product. *Perspicuity* measures how simple, clear, and easy to learn the product is. *Dependability* evaluates whether interactions with the product are predictable, secure, and meet user expectations. *Stimulation* gauges how interesting, exciting, and motivating the product is to use. Finally, *Novelty* reflects the innovation, inventiveness and creative design of the product.

In this study, I collected 10 valid questionnaires. Due to some participants leaving the *Fast-Slow* item blank, which did not correlate with their experiences, this item was excluded from the result presentation. To ensure clarity and ease of interpretation, I used a color-coding scheme: blue tones to represent positive emotions, red tones for negative emotions, and grey for neutral responses. Darker shades indicate stronger emotional intensity. The results were organized into six clusters based on the UEQ factors, with average scores calculated to represent the associated user experience (see Figure 5.2).

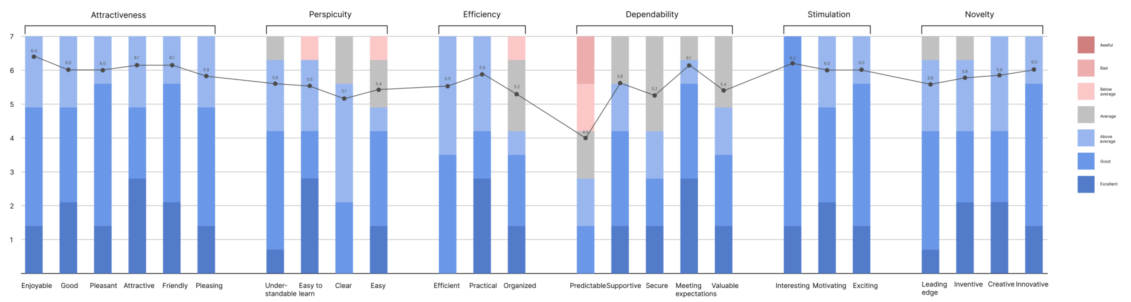

Figure 5.2: The results of UEQ

5.2.1 Ideo-Pleasure

Ideo-pleasure pertains to the aesthetics of a product and the values it embodies [140]. In this study, the factors of *Attractiveness*, *Stimulation*, and *Novelty* are considered to fall under this category, each reflecting aspects of aesthetic and value-based pleasure.

5.2.1.1 Attractiveness

The *Attractiveness* of the *Commuting Therapy* received the highest ratings, with all participants expressing positive feedback. This indicates that the aesthetic design of the animation, interface, and ambient lighting resonated strongly with participants, aligning with their aesthetic preferences.

Regarding the visual elements incorporating the nebula narrative, six participants expressed high satisfaction and aesthetic pleasure, noting that the design aligns well with the Polestar brand. The space-themed narrative was seen as reinforcing the brand's values. However, two participants suggested simplifying the design, with one recommending that the Nebula animation be made more abstract and feature lower saturation.

5.2.1.2 Stimulation and Novelty

The *Stimulation* of the *Commuting Therapy* was rated similarly to its *Attractiveness* factor, with the *Novelty* rated relatively lower. Participants found the in-car scent feature both interesting and motivating, with three out of ten having encountered this feature for the first time. Six participants expressed that the adaptive music feature was particularly desirable and exciting. Overall, participants viewed the *Commuting Therapy* concept as innovative and cutting-edge. Additionally, three participants specifically mentioned the dynamic ambient light feature when discussing their experiences.

5.2.2 Physio-Pleasure

Physio-pleasure arises from sensory experiences such as touch, taste, smell, and other sensual pleasures [140]. In this study, one aspect of *Stimulation* falls under Physio-pleasure. Participants noted that the strong scents and memorable visual stimuli experienced during the VR simulator experience contributed to an interesting and exciting experience, which they reflected in their QUE ratings. Notably, the aspects of physio-pleasure were discussed in detail in the previous subsection.

5.2.2.1 Psycho-Pleasure

Psycho-pleasure is derived from the successful completion of tasks, emphasizing how a product facilitates task completion and delivers a satisfying experience [140]. In this study, *Perspicuity*, *Efficiency*, and *Dependability* are categorized under Psycho-pleasure. These factors received notably low ratings, with *Dependability* being rated the lowest. Specifically, *Predictable* and *Secure* were identified as the most critically low items. Two participants expressed uncertainty about the effectiveness of the car's ability to accurately read their emotions and questioned whether they would appreciate the recommendations provided by the system. Additionally, two participants found the multisensory car system overly complex for their needs.

5.2.2.2 Socio-Pleasure

Socio-pleasure arises from the enjoyment of social interactions and the company of others [140]. In this study, socio-pleasure was primarily explored through brief interviews, focusing on how the product affects social interactions and the user's social standing. When asked *How does the product impact your interactions with other people during commutes?*, four participants noted that *Commuting Therapy* is a driver-centric experience, tailored to individual use. They indicated that accommodating multiple passengers with varying states could be challenging. Conversely, three participants believed the product could potentially stimulate social interaction, as it might prompt conversations about its unique functionalities, though such interactions would likely be short.

Regarding the question *If you were commuting with others, do you believe that this product could influence your social status or how others perceive you? Do you feel a sense of pride or distinction when using it?*, most participants responded positively. They felt that the sophisticated features and innovative design of the product could enhance their social status and create a sense of pride, as they believe these elements would be intriguing and noteworthy to others.

6

Discussion and conclusions

This thesis presents an emotion-based multisensory human-vehicle interaction system designed for leisure in a smart cabin that contributes to a more pleasurable commuting experience. One main research questions has been explored in this project: "How can a mundane commute be transformed into a more pleasurable experience through leisure experience?". Furthermore, two subsidiary research questions are proposed to explore emotion detection and regulation methods in vehicle, specifically Polestar cars, which are essential to make the design solution for the first research question into practice.

As shown in Figure 5.1 and Figure 5.2, the results indicate that the attitude for the proposed system *Commuting Therapy*, which is aimed for addressing the first research question, is generally positive. The results suggest that mundane time during commuting can be used to help users transition their emotional states and thus have a more pleasurable experience.

The two subsidiary research questions were explored and addressed through a comprehensive literature review. The technological settings and built-in device conditions in Polestar were used as criteria to refine the selection of methods and identify the most effective approach. To enhance the accuracy of emotion detection, *Commuting Therapy* integrates multiple methodologies, including physical and behavioral measurements, driving context factors, and self-reported scales. Furthermore, it employs multisensory strategies, such as visual, olfactory, auditory, and haptic modalities, to regulate emotional states. Addressing these two research questions was instrumental in shaping the design solution, *Commuting Therapy*.

6.1 Discussion and conclusions

Numerous studies have demonstrated the effectiveness of various sensory strategies in regulating emotions [53] [106] [105] [91]. However, research exploring the combined effects of multiple sensory strategies working together remains limited. This study addresses this gap by providing valuable insights into how different sensory stimuli (visual, olfactory, auditory, and haptic sensations) contribute to the overall driving experience.

The observed findings align with previous studies regarding the emotion regulation strategies. Visual stimuli [88] [4] [89] [90] [91], through the use of nebula animation and dynamic lighting, can create an environment that promotes relaxation and mental clarity. Similarly, olfactory stimuli [102] [104] [105] [103] can evoke positive memories and emotions, contributing to a serene atmosphere. Auditory stimuli [96] [72] [97] [98] [38] [53], particularly adaptive music, can help mask the noise of traffic and create a more pleasant auditory landscape. Lastly, tactile stimuli [107] [108] [76], such as haptic feedback and soft materials, enhance comfort and safety, further supporting a therapeutic driving experience. By integrating these sensory elements thoughtfully, designers can transform commuting from a mundane necessity into a pleasurable journey.

6.1.1 Visual stimuli

Colorful lighting have long been recognized as powerful tools for altering emotional states [128] [129] [114] [115]. For instance, warm lights such as red and orange-enriched white lights are known to evoke excitement and energy, while cooler lights like blue and green-enriched white lights promote calmness and relaxation. The study revealed that visual stimuli, particularly ambient lighting, play a crucial role in enhancing user experience and emotional responses during driving. Participants reported that variations in lighting effects were notably effective in reducing stress and increasing overall driving pleasure. Specifically, two participants experienced a calming effect from the blue-toned animations and ambient light. These findings are consistent with existing literature, which underscores the impact of visual elements on emotion regulation [116] [120] [114] [115] [121] [91] [92] [105].

Participants exhibited the most divergent attitudes towards the nebula animation, expressing a significant level of scepticism during the user study. The primary concerns revolved around potential driving distractions and the risk of drowsiness induced by certain animations or lighting effects. Many participants mentioned that they were satisfied with the existing ambient lights and did not feel the need for further dynamic patterns. This aligns with a study that found static lights received the highest satisfaction scores among users [124]. The variation in responses underscores the need to balance aesthetic appeal with safety considerations in the design of in-car lighting systems. By addressing these concerns through thoughtful design and providing customizable options, it may be possible to mitigate risks and enhance overall user satisfaction.

Below are several visual design suggestions derived from the user study.

1. **Nebula animation matching states**: Give users the autonomy to select preferable nebulae and pair different nebula types with various emotional states.

2. **Animation preferences**: Integrate the biophilic design elements, for instance, more abstract visuals such as underwater wildlife and rainforests, re-

laxing animations like galaxies, space, and waves of water, and animations with soft colors and movements.

3. **Ambient lighting effect**: Make the static light as a default setting, allowing various patterns. For further lights design suggestions, check the lights design guideline [124] in literature section.

4. **Personalisation**: Participants expressed a desire for control over visual settings, indicating that individual preferences play a significant role in how these stimuli are perceived.

6.1.2 Olfactory stimuli

Olfactory stimuli, though less prominently featured in the study, were nonetheless found to have a subtle yet significant impact on the driving experience. Participants noted that pleasant scents, such as those mimicking natural environments (e.g., pine forests or ocean breezes), contributed to a more positive and relaxing atmosphere. This is consistent with research indicating that certain smells can reduce stress and improve mood, thereby enhancing overall well-being [105] [106] [104].

Interestingly, the study found that the impact of smell was most pronounced when combined with other sensory stimuli, such as visuals and sound. This suggests that a multi-sensory approach could be more effective in creating an immersive and enjoyable driving environment. However, as with visual stimuli, personalisation is key. Participants indicated varying preferences for scents, with some expressing sensitivity to strong or synthetic odors. This underscores the importance of offering customizable scent options and ensuring that any olfactory system is flexible and user-controlled.

Below are several aroma design suggestions derived from the user study.

1. **Signature scents**: Develop unique Polestar scents that embody luxury and reinforce brand identity.

2. **Aroma customization**: Allow users to customize their in-car aroma experience.

3. **Diverse scent options**: Offer a variety of scents to cater to different customer preferences and enhance the overall driving experience.

6.1.3 Auditory stimuli

Music is a powerful tool for influencing emotions, and its integration into car systems was found to significantly enhance the driving experience by positively affecting mood and overall satisfaction [97]. While most participants responded positively to the adaptive music feature, noting its impact on mood regulation and driving enjoyment, there were some concerns. A few participants reported negative experiences due to mismatches in music type or volume.

Participants valued the convenience of automatically matching music to emotional states, as well as the discovery of new music through recommendations. However, they also expressed a desire for more personalized control over music settings, including automatic volume adjustments and the ability to choose alternative audio content like audiobooks or local radio. Older participants specifically highlighted the need for diverse audio options, suggesting integration with third-party apps.

Below are several auditory design suggestions derived from the user study.

1. **Adaptive music personalization**: Enhance the personalization options by allowing users to fine-tune music preferences and volume levels, ensuring the system matches their desired emotional states more accurately.

2. **Integration with third-party apps**: Expand the system's capabilities by integrating with different apps and supporting additional content like audiobooks and local radio, catering to diverse user preferences.

3. **Automatic volume adjustment**: Implement an automatic sound adjustment feature that adapts to individual preferences and external noise conditions, improving both the listening experience and overall comfort.

4. **Noise masking with music**: Consider the use of adaptive music as a tool for masking road noise, particularly for users who are sensitive to external sounds during driving.

6.1.4 Tactile stimuli

Tactile sensations, such as temperature adjustments and massage features, were generally well-received by participants. While most participants appreciated these features for their comfort and relaxation benefits, particularly during long commutes. However, a few expressed concerns about the potential for distraction and drowsiness, which highlights the need to balance comfort with safety in the design of tactile stimuli. Participants had positive feedback regarding the massage function, likening it to the comfort of a home environment. They found it particularly effective in reducing stress and enhancing the overall driving experience. However, there were suggestions to carefully calibrate these features to prevent them from being too distracting or overly relaxing, which could negatively impact driving performance.

Below are several tactile design suggestions based on the user study.

1. **Adjustable massage intensity**: Offer customizable massage settings to allow users to select the intensity that best suits their comfort level without causing distraction or drowsiness.

2. **Temperature control**: Provide precise temperature control with options to set individual preferences, ensuring comfort while minimizing the risk of inducing sleepiness.

3. **Integrated comfort settings**: Develop a system that seamlessly integrates tactile features, such as massage and temperature control, with other in-car stimuli to enhance the overall driving experience while maintaining focus and alertness.

6.1.5 Other design suggestions

Other design suggestions beyond the scope of sensations are listed as follows.

1. **Align with Brand Values**: Ensure the product embodies Polestar's core values of sustainability, high performance, and luxury. Focus on highlighting features that reflect environmental responsibility, technological innovation, and premium quality to resonate with brand expectations.

2. **Improve Dependability**: Address concerns regarding the system's predictability and security. Enhance the accuracy of emotion detection and ensure that recommendations are reliable and relevant to improve user trust.

3. **Simplify Interaction**:Streamline the system's complexity to make it more user-friendly. Ensure that features are intuitive and that users can easily interact with the system without feeling overwhelmed.

4. **Enhance Social Status Impact**: Continue to emphasize sophisticated and cutting-edge features that could enhance users' sense of pride and social standing. Ensure that the system's design reflects modernity and exclusivity to bolster its appeal in social contexts.

5. **Privacy Considerations**: Consider situational context and potentially limit the visibility of emotional feedback to preserve privacy and avoid unintended emotional impacts on the driver and passengers.

The concept of *Commuting Therapy* was evaluated using a VR car simulator, where participant feedback on the concept and suggestions for future improvements were collected and analyzed. The results align with the findings in previous literature review, demonstrating that sensory enhancements such as soothing visuals, pleasant scents, calming sounds, and comfortable tactile experiences can help users achieve the desired state, turning the vehicle into a space for transition. Future research should continue to explore the interplay between different sensory stimuli and their combined effects on user experience. By deepening the understanding of these interactions, designers can create more engaging, pleasurable, and ultimately safer driving environments.

6.2 Future work

While this study provides valuable insights, it also highlights several areas for future research. First and foremost, further investigation is needed into the effects of precise lighting characteristics on emotional responses is crucial. Understanding how dynamic variables such as color, brightness, placement, and lighting patterns influence emotions—measured through valence, arousal, and dominance—is essential for effectively using colored lights in emotion regulation. Additionally, understanding how individual preferences for sensory stimuli can be better catered to will be key in creating more effective and enjoyable commuting therapy environments. This includes developing adaptive systems that learn from and respond to the user's emotional state, preferences, and driving conditions in real time.

Furthermore, research should investigate the long-term effects of multisensory stimuli on mental health and well-being during commuting. For instance, longitudinal studies could examine how sustained exposure to therapeutic driving environments impacts stress levels, cognitive function, and overall mental health. Another area worth exploring is the integration of advanced technologies such as virtual reality (VR) and augmented reality (AR) to create more immersive and interactive sensory experiences in the vehicle.

Finally, the concept of commuting therapy could be extended beyond the individual to consider its broader societal impacts. For example, how might widespread adoption of therapeutic driving environments influence overall public health, productivity, and even traffic patterns? Understanding these macro-level effects could help in designing policies and infrastructure that support healthier and more sustainable commuting practices.

In conclusion, the integration of multisensory stimuli into vehicle design offers a promising avenue for enhancing the driving experience and transforming commuting into a form of therapy. By continuing to explore and refine these approaches, I can unlock new possibilities to improve both individual well-being and societal outcomes through a more thoughtful and human-centered design.

6.3 The practical implications of the research

In the highly competitive electric vehicle market, user experience increasingly determines purchasing decisions [7]. This research presents the potential of integrating multiple sensory modalities to regulate emotions, offering new avenues for design professionals, particularly those specializing in smart cabin user experiences. By examining participants' responses to various sensory stimuli and their suggestions for sensory design, this study provides valuable insights that designers can incorporate to enhance their work. Considering these insights can help designers refine their approaches and create more engaging and emotionally supportive vehicle environments.

6.4 Limitations

6.4.1 Precise Emotion Regulation

Despite extensive research, there remains no universally accepted model for regulating emotions. The lack of a precise and agreed-upon emotional regulation framework complicates the interpretation and application of emotion regulation strategies.

6.4.2 Technological Issues of In-car Emotion Detection

Emotion detection technologies face several limitations. Camera-based methods are sensitive to lighting conditions and occlusions, which can impact their accuracy [89]. Physiological sensing methods, on the other hand, are subject to individual variability and can be affected by muscle movements and artifacts [15].

6.4.3 Color and colored lights

Although extensive research has demonstrated that colors can affect human emotions, and even utilized models like PAD to numerically quantify these effects, direct evidence linking lighting colors to emotional responses remains sparse. While there is substantial research on the calming effects of blue light [40] [90] [89] [4] [124], there is no comprehensive theoretical framework that connects specific light colors to distinct emotional responses.

Most studies have focused on the impact of light on health, well-being, mood, and performance [113], with a notable emphasis on the calming effects of blue light. However, the emotional effects of many other colors of light, and how they may differ from the colors themselves, remain unclear. Furthermore, while blue light is generally perceived positively, this may not apply universally. The context can significantly alter perceptions; for instance, blue-colored objects, such as blue food or hair, might not elicit the same positive emotional response [126].

My assumption that colors and colored lights produce identical emotional effects might be overly simplistic. The effectiveness of color-based stimuli can vary based on context and how they are used. Further research is needed to develop a theoretical framework that accurately links specific lighting colors to emotional responses in different settings.

6.4.4 Privacy Considerations in Emotion Sensing

The use of physiological sensing for emotion detection raises privacy concerns. Emotions are inherently private, and while physiological signals are harder to conceal, they may undermine individuals' control over self-expression. The design of emotion-sensitive systems should account for privacy, especially in contexts where multiple passengers are present.

Bibliography

[1] PrEmo Tool. Premo tool - measure product emotions. https://www.premotool.com/. Accessed: 2024-06-10.

[2] James A Russell. A circumplex model of affect. *Journal of personality and social psychology*, 39(6):1161, 1980.

[3] Robert Mearns Yerkes, John D Dodson, et al. The relation of strength of stimulus to rapidity of habit-formation. *Editorial Office, Denison University Granville, OH, USA*, 1908.

[4] Michael Braun, Jonas Schubert, Bastian Pfleging, and Florian Alt. Improving driver emotions with affective strategies. *Multimodal Technologies and Interaction*, 3(1):21, 2019.

[5] Felix Roeckle, Raphael Hahn, Sebastian Stegmueller, and Florian Herrmann. Features of future autonomous cars: beyond interior design. In *Conference on Future Automotive Technology*, 2018.

[6] Yazdan Mansourian. How passionate people seek and share various forms of information in their serious leisure. *Journal of the Australian Library and Information Association*, 69(1):17–30, 2020.

[7] Moritz Körber, Armin Eichinger, Klaus Bengler, and Cristina Olaverri-Monreal. User experience evaluation in an automotive context. In *2013 IEEE Intelligent Vehicles Symposium Workshops (IV Workshops)*, pages 13–18, 2013.

[8] Stephanie Balters, Matthew L Mauriello, So Yeon Park, James A Landay, and Pablo E Paredes. Calm commute: Guided slow breathing for daily stress management in drivers. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, 4(1):1–19, 2020.

[9] Nicole Perterer, Christiane Moser, Alexander Meschtscherjakov, Alina Krischkowsky, and Manfred Tscheligi. Activities and technology usage while driving: A field study with private short-distance car commuters. In *Pro-*

ceedings of the 9th Nordic Conference on Human-Computer Interaction, pages 1–10, 2016.

[10] Sven Krome, Steffen P Walz, and Stefan Greuter. Contextual inquiry of future commuting in autonomous cars. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, pages 3122–3128, 2016.

[11] Baiba Pudāne and Gonçalo Correia. On the impact of vehicle automation on the value of travel time while performing work and leisure activities in a car: Theoretical insights and results from a stated preference survey–a comment. *Transportation Research Part A: Policy and Practice*, 132:324–328, 2020.

[12] Manzoor Ahmed Khan, Hesham El Sayed, Sumbal Malik, Talha Zia, Jalal Khan, Najla Alkaabi, and Henry Ignatious. Level-5 autonomous driving—are we there yet? a review of research literature. *ACM Computing Surveys (CSUR)*, 55(2):1–38, 2022.

[13] Sven Krome, Jussi Holopainen, and Stefan Greuter. Autogym: an exertion game for autonomous driving. In *Proceedings of the Annual Symposium on Computer-Human Interaction in Play*, pages 33–42, 2017.

[14] Zoë Terken, Roy Haex, Luuk Beursgens, Elvira Arslanova, Maria Vrachni, Jacques Terken, and Dalila Szostak. Unwinding after work: an in-car mood induction system for semi-autonomous driving. In *Proceedings of the 5th international conference on automotive user interfaces and interactive vehicular applications*, pages 246–249, 2013.

[15] Desney Tan and Anton Nijholt. *Brain-computer interfaces and human-computer interaction*. Springer, 2010.

[16] David E Dass Jr, Alex Uyttendaele, and Jacques Terken. Haptic in-seat feedback for lane departure warning. In *Proceedings of the 5th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, pages 258–261, 2013.

[17] Melanie Berger, Aditya Dandekar, Regina Bernhaupt, and Bastian Pfleging. An ar-enabled interactive car door to extend in-car infotainment systems for rear seat passengers. In *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems*, pages 1–6, 2021.

[18] Shaoyue Wen, Songming Ping, Jialin Wang, Hai-Ning Liang, Xuhai Xu, and Yukang Yan. Adaptivevoice: Cognitively adaptive voice interface for driving assistance. In *Proceedings of the CHI Conference on Human Factors in Computing Systems*, pages 1–18, 2024.

[19] Dmitrijs Dmitrenko, Emanuela Maggioni, and Marianna Obrist. I smell trouble: using multiple scents to convey driving-relevant information. In *Proceedings of the 20th ACM international conference on multimodal interaction*, pages 234–238, 2018.

[20] Danny Oude Bos et al. Eeg-based emotion recognition. *The influence of visual and auditory stimuli*, 56(3):1–17, 2006.

[21] Sriparna Saha, Shreyasi Datta, Amit Konar, and Ramadoss Janarthanan. A study on emotion recognition from body gestures using kinect sensor. In *2014 international conference on communication and signal processing*, pages 056–060. IEEE, 2014.

[22] Wenbo Li, Guanzhong Zeng, Juncheng Zhang, Yan Xu, Yang Xing, Rui Zhou, Gang Guo, Yu Shen, Dongpu Cao, and Fei-Yue Wang. Cogemonet: A cognitive-feature-augmented driver emotion recognition model for smart cockpit. *IEEE Transactions on Computational Social Systems*, 9(3):667–678, 2022.

[23] Joseph F Coughlin, Bryan Reimer, and Bruce Mehler. Monitoring, managing, and motivating driver safety and well-being. *IEEE Pervasive Computing*, 10(3):14–21, 2011.

[24] Henry Togwell, Mark McGill, Graham Wilson, Daniel Medeiros, and Stephen Anthony Brewster. In-car gaming: Exploring the use of ar headsets to leverage passenger travel environments for mixed reality gameplay. In *CHI Conference on Human Factors in Computing Systems Extended Abstracts*, pages 1–7, 2022.

[25] Dimitrios Gkouskos, Ingrid Pettersson, MariAnne Karlsson, and Fang Chen. Exploring user experience in the wild: facets of the modern car. In *Design, User Experience, and Usability: Interactive Experience Design: 4th International Conference, DUXU 2015, Held as Part of HCI International 2015, Los Angeles, CA, USA, August 2-7, 2015, Proceedings, Part III 4*, pages 450–461. Springer, 2015.

[26] Thomas M Deserno. Transforming smart vehicles and smart homes into private diagnostic spaces. In *Proceedings of the 2020 2nd Asia Pacific Information Technology Conference*, pages 165–171, 2020.

[27] Stephanie Balters, James A Landay, and Pablo E Paredes. On-road guided slow breathing interventions for car commuters. In *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems*, pages 1–5, 2019.

[28] Zoe M Becerra, Brittany Holthausen, and Bruce N Walker. Bringing the thrill

to automated vehicles: an evaluation of thrill-seeking driving displays. In *Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications: Adjunct Proceedings*, pages 381–386, 2019.

[29] Matthew Lakier, Lennart E Nacke, Takeo Igarashi, and Daniel Vogel. Cross-car, multiplayer games for semi-autonomous driving. In *Proceedings of the annual symposium on computer-human interaction in play*, pages 467–480, 2019.

[30] Sven Krome, Joshua Batty, Stefan Greuter, and Jussi Holopainen. Autojam: Exploring interactive music experiences in stop-and-go traffic. In *Proceedings of the 2017 conference on designing interactive systems*, pages 441–450, 2017.

[31] Ronald Schroeter, Andry Rakotonirainy, and Marcus Foth. The social car: new interactive vehicular applications derived from social media and urban informatics. In *Proceedings of the 4th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, pages 107–110, 2012.

[32] Martin Knobel, Marc Hassenzahl, Melanie Lamara, Tobias Sattler, Josef Schumann, Kai Eckoldt, and Andreas Butz. Clique trip: Feeling related in different cars. In *Proceedings of the designing interactive systems conference*, pages 29–37, 2012.

[33] Karl-Petter Ðkesson and Andreas Nilsson. Designing leisure applications for the mundane car-commute. *Personal and Ubiquitous Computing*, 6:176–187, 2002.

[34] Alan E Pisarski. Commuting in america. a national report on commuting patterns and trends. *Psychol*, 1987.

[35] Liselott Brunnberg. The road rager: making use of traffic encounters in a mobile multiplayer game. In *Proceedings of the 3rd international conference on Mobile and ubiquitous multimedia*, pages 33–39, 2004.

[36] Myounghoon Jeon, Jung-Bin Yim, and Bruce N Walker. An angry driver is not the same as a fearful driver: effects of specific negative emotions on risk perception, driving performance, and workload. In *Proceedings of the 3rd international conference on automotive user interfaces and interactive vehicular applications*, pages 137–142, 2011.

[37] Daniela Wurhofer, Alina Krischkowsky, Marianna Obrist, Evangelos Karapanos, Evangelos Niforatos, and Manfred Tscheligi. Everyday commuting: Prediction, actual experience and recall of anger and frustration in the car. In *Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, pages 233–240, 2015.

[38] Yueyan Zhu, Ying Wang, Guofa Li, and Xiang Guo. Recognizing and releasing drivers' negative emotions by using music: evidence from driver anger. In *Adjunct proceedings of the 8th international conference on automotive user interfaces and interactive vehicular applications*, pages 173–178, 2016.

[39] Myounghoon Jeon. Emotions and affect in human factors and human–computer interaction: Taxonomy, theories, approaches, and methods. *Emotions and affect in human factors and human-computer interaction*, pages 3–26, 2017.

[40] Taesu Kim, Yeongwoo Kim, Hyeongseok Jeon, Chul-Soo Choi, and Hyeon-Jeong Suk. Emotional response to in-car dynamic lighting. *International journal of automotive technology*, 22:1035–1043, 2021.

[41] Dacher Keltner, Disa Sauter, Jessica Tracy, and Alan Cowen. Emotional expression: Advances in basic emotion theory. *Journal of nonverbal behavior*, 43:133–160, 2019.

[42] Michael Braun and Florian Alt. Affective assistants: A matter of states and traits. In *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems*, pages 1–6, 2019.

[43] Michaela Allaby and Charlene S Shannon. "i just want to keep in touch": Adolescents' experiences with leisure-related smartphone use. *Journal of Leisure Research*, 51(3):245–263, 2020.

[44] Bastian Pfleging, Maurice Rang, and Nora Broy. Investigating user needs for non-driving-related activities during automated driving. In *Proceedings of the 15th international conference on mobile and ubiquitous multimedia*, pages 91–99, 2016.

[45] Petra Sundstrom, Axel Baumgartner, Elke Beck, Christine Döttlinger, Martin Murer, Ivana Randelshofer, David Wilfinger, Alexander Meschtscherjakov, and Manfred Tscheligi. Gaming to sit safe: the restricted body as an integral part of gameplay. In *Proceedings of the 2014 conference on Designing interactive systems*, pages 715–724, 2014.

[46] Nora Broy, Sebastian Goebl, Matheus Hauder, Thomas Kothmayr, Michael Kugler, Florian Reinhart, Martin Salfer, Kevin Schlieper, and Elisabeth André. A cooperative in-car game for heterogeneous players. In *Proceedings of the 3rd international conference on automotive user interfaces and interactive vehicular applications*, pages 167–176, 2011.

[47] Liselott Brunnberg, Oskar Juhlin, and Anton Gustafsson. Games for passengers: accounting for motion in location-based applications. In *Proceedings of the 4th International Conference on Foundations of Digital Games*, pages

26–33, 2009.

[48] Kohei Matsumura and David S Kirk. On active passengering: Supporting in-car experiences. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, 1(4):1–23, 2018.

[49] Michael J Walsh. Driving to the beat of one's own hum: automobility and musical listening. In *Studies in symbolic interaction*, volume 35, pages 201–221. Emerald Group Publishing Limited, 2010.

[50] Kai Eckoldt and Benjamin N.N. Schulz. The car as a musical instrument: Drumming together as a positive experience; [das auto als musikinstrument: gemeinsames trommeln als positives erlebnis]. *i-com*, 8(1):83 – 85, 2009. Cited by: 3.

[51] Sebastian Zepf, Po-Wen Kao, Jan-Peter Krämer, and Philipp Scholl. Breath-triggered haptic and acoustic guides to support effortless calm breathing. In *2021 43rd Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC)*, pages 1796–1800. IEEE, 2021.

[52] Sebastian Zepf, Neska El Haouij, Jinmo Lee, Asma Ghandeharioun, Javier Hernandez, and Rosalind W Picard. Studying personalized just-in-time auditory breathing guides and potential safety implications during simulated driving. In *Proceedings of the 28th ACM Conference on User Modeling, Adaptation and Personalization*, pages 275–283, 2020.

[53] Wenbo Li, Guofa Li, Ruichen Tan, Cong Wang, Zemin Sun, Ying Li, Gang Guo, Dongpu Cao, and Keqiang Li. Review and perspectives on human emotion for connected automated vehicles. *Automotive Innovation*, 7(1):4–44, 2024.

[54] Richard S Lazarus. *Emotion and adaptation*. Oxford University Press, 1991.

[55] Paul Ekman. An argument for basic emotions. *Cognition & emotion*, 6(3-4):169–200, 1992.

[56] Robert Plutchik. The nature of emotions: Human emotions have deep evolutionary roots, a fact that may explain their complexity and provide tools for clinical practice. *American scientist*, 89(4):344–350, 2001.

[57] Pieter Desmet and Steven Fokkinga. Beyond maslow's pyramid: Introducing a typology of thirteen fundamental needs for human-centered design. *Multimodal technologies and interaction*, 4(3):38, 2020.

[58] James A Russell and Albert Mehrabian. Evidence for a three-factor theory of emotions. *Journal of research in Personality*, 11(3):273–294, 1977.

[59] Paul Ekman and Wallace V Friesen. Constants across cultures in the face and emotion. *Journal of personality and social psychology*, 17(2):124, 1971.

[60] James A Russell. Is there universal recognition of emotion from facial expression? a review of the cross-cultural studies. *Psychological bulletin*, 115(1):102, 1994.

[61] Ursula Hess, Rainer Banse, and Arvid Kappas. The intensity of facial expression is determined by underlying affective state and social situation. *Journal of personality and social psychology*, 69(2):280, 1995.

[62] Zhihong Zeng, Maja Pantic, Glenn I Roisman, and Thomas S Huang. A survey of affect recognition methods: audio, visual and spontaneous expressions. In *Proceedings of the 9th international conference on Multimodal interfaces*, pages 126–133, 2007.

[63] Cynthia M Whissell. The dictionary of affect in language. In *The measurement of emotions*, pages 113–131. Elsevier, 1989.

[64] Siddique Latif, Adnan Qayyum, Muhammad Usman, and Junaid Qadir. Cross-lingual speech emotion recognition: Urdu vs. western languages. In *Proceedings of the 2018 International Conference on Frontiers of Information Technology (FIT)*, pages 88–93. IEEE, 2018.

[65] Jo-Anne Bachorowski and Michael J Owren. Vocal expressions of emotion. *Handbook of emotions*, 3:196–210, 2008.

[66] Seliz Gülsen Karadoğan and Jan Larsen. Combining semantic and acoustic features for valence and arousal recognition in speech. In *2012 3rd International Workshop on Cognitive Information Processing (CIP)*, pages 1–6. IEEE, 2012.

[67] Donald Glowinski, Marcello Mortillaro, Klaus Scherer, Nele Dael, Gualtiero Volpe, and Antonio Camurri. Towards a minimal representation of affective gestures. In *2015 international conference on affective computing and intelligent interaction (ACII)*, pages 498–504. IEEE, 2015.

[68] Ronak Kosti, Jose M Alvarez, Adria Recasens, and Agata Lapedriza. Emotion recognition in context. In *Proceedings of the IEEE conference on computer vision and pattern recognition*, pages 1667–1675, 2017.

[69] Hatice Gunes and Massimo Piccardi. Affect recognition from face and body: early fusion vs. late fusion. In *2005 IEEE international conference on systems, man and cybernetics*, volume 4, pages 3437–3443. IEEE, 2005.

[70] Ginevra Castellano, Santiago D Villalba, and Antonio Camurri. Recognising

human emotions from body movement and gesture dynamics. In *International conference on affective computing and intelligent interaction*, pages 71–82. Springer, 2007.

[71] Pramila Rani, Changchun Liu, Nilanjan Sarkar, and Eric Vanman. An empirical study of machine learning techniques for affect recognition in human–robot interaction. *Pattern Analysis and Applications*, 9:58–69, 2006.

[72] Michael Braun, Bastian Pfleging, and Florian Alt. A survey to understand emotional situations on the road and what they mean for affective automotive uis. *Multimodal Technologies and Interaction*, 2(4):75, 2018.

[73] Sebastian Zepf, Monique Dittrich, Javier Hernandez, and Alexander Schmitt. Towards empathetic car interfaces: Emotional triggers while driving. In *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems*, pages 1–6, 2019.

[74] Myounghoon Jeon and Bruce N Walker. What to detect? analyzing factor structures of affect in driving contexts for an emotion detection and regulation system. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, volume 55, pages 1889–1893. SAGE Publications Sage CA: Los Angeles, CA, 2011.

[75] Pieter MA Desmet, Paul Hekkert, and Jan J Jacobs. When a car makes you smile: development and application of an instrument to measure product emotions. *Advances in consumer research*, 27(1), 2000.

[76] Rasshofer Schmidt, Decke. Correlation between subjective driver state measures and psychophysiological and vehicular data in simulated driving. In *In Proceedings of the 2016 IEEE Intelligent Vehicles Symposium (IV), Gothenburg, Sweden*, page 19–22, 2016.

[77] Ochs Schmidt and Bullinger Decke. Evaluating drivers' states in sleepiness countermeasures experiments using physiological and eye data–hybrid logistic and linear regression model. In *In Proceedings of the 9th International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design: Driving Assessment 2017, Manchester, VT, USA*, page 26–29, 2017.

[78] Khamis Hassib, Shirazi Schneegass, and Alt. Investigating user needs for biosensing and affective wearables. In *In Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems, San Jose, CA, USA, 7–12 May 2016; ACM: New York, NY, USA*, page 7–12, 2016.

[79] Ntouvas Katsis and Fotiadis Bafas. Assessment of muscle fatigue during driving using surface emg. In *In: Proceedings of the IASTED BioEng 2004*, volume 262, 2004.

[80] Zec Solovey, Reimer Garcia Perez, and Mehler. Classifying driver workload using physiological and driving performance data: two field studies. In *In: Proceedings of the CHI 2014*, page 4057–4066, 2014.

[81] Erin T. Solovey, Marin Zec, Enrique Abdon Garcia Perez, Bryan Reimer, and Bruce Mehler. Classifying driver workload using physiological and driving performance data: two field studies. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '14, page 4057–4066, New York, NY, USA, 2014. Association for Computing Machinery.

[82] Mariam Hassib, Max Pfeiffer, Stefan Schneegass, Michael Rohs, and Florian Alt. Emotion actuator: Embodied emotional feedback through electroencephalography and electrical muscle stimulation. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, CHI '17, page 6133–6146, New York, NY, USA, 2017. Association for Computing Machinery.

[83] Jeon Riener and Frison Alvarez. Driver in the loop: best practices in automotive sensing and feedback mechanisms. *Meixner, G., M uller, C. (eds.) Automotive User Interfaces.*, 42(1):295–323, 2017.

[84] Albert Mehrabian. Pleasure-arousal-dominance: A general framework for describing and measuring individual differences in temperament. *Current Psychology*, 14:261–292, 1996.

[85] Khamis Hassib, Shirazi Schneegass, and Alt. A method to infer emotions from facial action units. In *In Proceedings of the 2011 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), Prague, Czech Republic*, page 22–27, 2011.

[86] Althoff Hoch and Rigoll McGlaun. Bimodal fusion of emotional data in an automotive environment. In *In Proceedings of the IEEE International Conference on Acoustics, Speech, and Signal Processing, Philadelphia, PA, USA*, page 23, 2005.

[87] James J Gross. Emotion regulation in adulthood: Timing is everything. *Current directions in psychological science*, 10(6):214–219, 2001.

[88] Ewa Siedlecka and Thomas F Denson. Experimental methods for inducing basic emotions: A qualitative review. *Emotion Review*, 11(1):87–97, 2019.

[89] Mariam Hassib, Michael Braun, Bastian Pfleging, and Florian Alt. Detecting and influencing driver emotions using psycho-physiological sensors and ambient light. In *IFIP Conference on Human-Computer Interaction*, pages 721–742. Springer, 2019.

[90] Elena Spiridon and Stephen Fairclough. The effects of ambient blue light on anger levels: Applications in the design of unmanned aircraft gcs. *International Journal of Unmanned Systems Engineering*, 5(3):53–69, 2017.

[91] Andreas Löcken, Wilko Heuten, and Susanne Boll. Enlightening drivers: A survey on in-vehicle light displays. In *Proceedings of the 8th international conference on automotive user interfaces and interactive vehicular applications*, pages 97–104, 2016.

[92] Wenbo Li, Bingbing Zhang, Peizhi Wang, Chen Sun, Guanzhong Zeng, Qiuyang Tang, Gang Guo, and Dongpu Cao. Visual-attribute-based emotion regulation of angry driving behaviors. *IEEE Intelligent Transportation Systems Magazine*, 14(3):10–28, 2021.

[93] Michael Braun, Ronee Chadowitz, and Florian Alt. User experience of driver state visualizations: A look at demographics and personalities. In *Human-Computer Interaction–INTERACT 2019: 17th IFIP TC 13 International Conference, Paphos, Cyprus, September 2–6, 2019, Proceedings, Part IV 17*, pages 158–176. Springer, 2019.

[94] Mark B Johnson and Scott McKnight. Warning drivers about potential congestion as a means to reduce frustration-driven aggressive driving. *Traffic injury prevention*, 10(4):354–360, 2009.

[95] Nicola Dibben and Victoria J Williamson. An exploratory survey of in-vehicle music listening. *Psychology of Music*, 35(4):571–589, 2007.

[96] Chinmayi Bankar, Aditya Bhide, Anuja Kulkarni, Chirag Ghube, and Mangesh Bedekar. Driving control using emotion analysis via eeg. In *2018 ieee punecon*, pages 1–7. IEEE, 2018.

[97] Erion Çano, Riccardo Coppola, Eleonora Gargiulo, Marco Marengo, and Maurizio Morisio. Mood-based on-car music recommendations. In *Industrial Networks and Intelligent Systems: Second International Conference, INISCOM 2016, Leicester, UK, October 31–November 1, 2016, Proceedings 2*, pages 154–163. Springer, 2017.

[98] Florian Eyben, Martin Wöllmer, Tony Poitschke, Björn Schuller, Christoph Blaschke, Berthold Färber, and Nhu Nguyen-Thien. Emotion on the road—necessity, acceptance, and feasibility of affective computing in the car. *Advances in Human-Computer Interaction*, 2010(1):263593, 2010.

[99] Marjolein D Van Der Zwaag, Chris Dijksterhuis, Dick De Waard, Ben LJM Mulder, Joyce HDM Westerink, and Karel A Brookhuis. The influence of music on mood and performance while driving. *Ergonomics*, 55(1):12–22, 2012.

[100] Kimberly Sena Moore. A systematic review on the neural effects of music on emotion regulation: Implications for music therapy practice. *Journal of music therapy*, 50(3):198–242, 2013.

[101] Anna Aljanaki, Yi-Hsuan Yang, and Mohammad Soleymani. Developing a benchmark for emotional analysis of music. *PloS one*, 12(3):e0173392, 2017.

[102] Pavlna Lenochova, Pavla Vohnoutova, S Craig Roberts, Elisabeth Oberzaucher, Karl Grammer, and Jan Havlivcek. Psychology of fragrance use: perception of individual odor and perfume blends reveals a mechanism for idiosyncratic effects on fragrance choice. *PloS one*, 7(3):e33810, 2012.

[103] Andrew J Johnson. Cognitive facilitation following intentional odor exposure. *Sensors*, 11:5469–5488, 2011.

[104] Bryan Raudenbush, Rebecca Grayhem, Tom Sears, and Ian Wilson. Effects of peppermint and cinnamon odor administration on simulated driving alertness, mood and workload. *North American Journal of Psychology*, 11(2), 2009.

[105] Masria Mustafa, Norazni Rustam, and Rosfaiizah Siran. The impact of vehicle fragrance on driving performance: what do we know? *Procedia-Social and Behavioral Sciences*, 222:807–815, 2016.

[106] Dmitrijs Dmitrenko, Emanuela Maggioni, Giada Brianza, Brittany E Holthausen, Bruce N Walker, and Marianna Obrist. Caroma therapy: pleasant scents promote safer driving, better mood, and improved well-being in angry drivers. In *Proceedings of the 2020 chi conference on human factors in computing systems*, pages 1–13, 2020.

[107] Elisabeth Schmidt and Angelika C Bullinger. Mitigating passive fatigue during monotonous drives with thermal stimuli: Insights into the effect of different stimulation durations. *Accident Analysis & Prevention*, 126:115–121, 2019.

[108] Javier Hernandez, Daniel McDuff, Xavier Benavides, Judith Amores, Pattie Maes, and Rosalind Picard. Autoemotive: bringing empathy to the driving experience to manage stress. In *Proceedings of the 2014 companion publication on Designing interactive systems*, pages 53–56. IEEE, 2014.

[109] Julia Winzen, Frank Albers, and Claudia Marggraf-Micheel. The influence of coloured light in the aircraft cabin on passenger thermal comfort. *Lighting Research & Technology*, 46(4):465–475, 2014.

[110] Robert John Lewinski. An investigation of individual responses to chromatic illumination. *The Journal of Psychology*, 6(1):155–160, 1938.

[111] Rikard Küller, Seifeddin Ballal, Thorbjörn Laike, Byron Mikellides, and Gra-

ciela Tonello. The impact of light and colour on psychological mood: a cross-cultural study of indoor work environments. *Ergonomics*, 49(14):1496–1507, 2006.

[112] Gena Glickman, Brenda Byrne, Carissa Pineda, Walter W Hauck, and George C Brainard. Light therapy for seasonal affective disorder with blue narrow-band light-emitting diodes (leds). *Biological psychiatry*, 59(6):502–507, 2006.

[113] Stephen Westland, Qianqian Pan, and SooJin Lee. A review of the effects of colour and light on non-image function in humans. *Coloration Technology*, 133(5):349–361, 2017.

[114] Michael Terman and Jiuan Su Terman. Light therapy for seasonal and nonseasonal depression: efficacy, protocol, safety, and side effects. *CNS spectrums*, 10(8):647–663, 2005.

[115] Veronika Leichtfried, Maria Mair-Raggautz, Viktoria Schaeffer, Angelika Hammerer-Lercher, Gerald Mair, Christian Bartenbach, Markus Canazei, and Wolfgang Schobersberger. Intense illumination in the morning hours improved mood and alertness but not mental performance. *Applied Ergonomics*, 46:54–59, 2015.

[116] M Canazei and E Weiss. The influence of light on mood and emotion. *Handbook of Psychology of Emotions: Recent Theoretical Perspectives and Novel Empirical Findings; Nova Science Publishers: Hauppauge, NY, USA*, 1:297–306, 2013.

[117] Yousef Al Horr, Mohammed Arif, Amit Kaushik, Ahmed Mazroei, Martha Katafygiotou, and Esam Elsarrag. Occupant productivity and office indoor environment quality: A review of the literature. *Building and environment*, 105:369–389, 2016.

[118] Steven W Lockley, Erin E Evans, Frank AJL Scheer, George C Brainard, Charles A Czeisler, and Daniel Aeschbach. Short-wavelength sensitivity for the direct effects of light on alertness, vigilance, and the waking electroencephalogram in humans. *Sleep*, 29(2):161–168, 2006.

[119] Gilles Vandewalle, Evelyne Balteau, Christophe Phillips, Christian Degueldre, Vincent Moreau, Virginie Sterpenich, Geneviève Albouy, Annabelle Darsaud, Martin Desseilles, Thien Thanh Dang-Vu, et al. Daytime light exposure dynamically enhances brain responses. *Current Biology*, 16(16):1616–1621, 2006.

[120] Thomas Kantermann, Sebastian Forstner, Martin Halle, Luc Schlangen, Till Roenneberg, and Arno Schmidt-Trucksäss. The stimulating effect of bright light on physical performance depends on internal time. *PLoS One*,

7(7):e40655, 2012.

[121] Georg Hoffmann, Veronika Gufler, Andrea Griesmacher, Christian Bartenbach, Markus Canazei, Siegmund Staggl, and Wolfgang Schobersberger. Effects of variable lighting intensities and colour temperatures on sulphatoxymelatonin and subjective mood in an experimental office workplace. *Applied Ergonomics*, 39(6):719–728, 2008.

[122] Robert A Baron, Mark S Rea, and Susan G Daniels. Effects of indoor lighting (illuminance and spectral distribution) on the performance of cognitive tasks and interpersonal behaviors: The potential mediating role of positive affect. *Motivation and emotion*, 16(1):1–33, 1992.

[123] Rikard Kuller and Thorbjorn Laike. The impact of flicker from fluorescent lighting on well-being, performance and physiological arousal. *Ergonomics*, 41(4):433–447, 1998.

[124] Taesu Kim, Gyunpyo Lee, Minjung Park, Hong Min Lee, Ji-Woo Park, and Hyeon-Jeong Suk. User responses to dynamic light in automobiles with eeg and self-assessments. *IEEE Access*, 10:123847–123857, 2022.

[125] Luca Caberletti, Kai Elfmann, M Kummel, and Christoph Schierz. Influence of ambient lighting in a vehicle interior on the driver's perceptions. *Lighting Research & Technology*, 42(3):297–311, 2010.

[126] Patricia Valdez and Albert Mehrabian. Effects of color on emotions. *Journal of experimental psychology: General*, 123(4):394, 1994.

[127] J. P. Guilford. Affective value of color as a function of hue, tint, and chroma. *Journal of Experimental Psychology*, 17:342–370, 1934.

[128] Guilford and Smith. A system of color preferences. *American Journal of Psychology*, 72:487–502, 1959.

[129] Guilford and Smith. The meaning of color. *Journal of General Psychology*, 67:89–99, 1962.

[130] Francis M Adams and Charles E Osgood. A cross-cultural study of the affective meanings of color. *Journal of cross-cultural psychology*, 4(2):135–156, 1973.

[131] Hanneke Hooft van Huysduynen, Jacques Terken, Alexander Meschtscherjakov, Berry Eggen, and Manfred Tscheligi. Ambient light and its influence on driving experience. In *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, pages 293–301, 2017.

[132] Patrice Bourgin and Jeffrey Hubbard. Alerting or somnogenic light: pick your color. *PLoS biology*, 14(8):e2000111, 2016.

[133] Torbjörn Åkerstedt, Ulf Landström, Marianne Byström, Bertil Nordström, and Roger Wibom. Bright light as a sleepiness prophylactic: a laboratory study of subjective ratings and eeg. *Perceptual and motor skills*, 97(3):811–819, 2003.

[134] Pietro Badia, Brent Myers, Maren Boecker, Janice Culpepper, and JR Harsh. Bright light effects on body temperature, alertness, eeg and behavior. *Physiology & behavior*, 50(3):583–588, 1991.

[135] Antoine U Viola, Lynette M James, Luc JM Schlangen, and Derk-Jan Dijk. Blue-enriched white light in the workplace improves self-reported alertness, performance and sleep quality. *Scandinavian journal of work, environment & health*, pages 297–306, 2008.

[136] Kyungah Choi, Cheong Shin, Taesu Kim, Hyun Jung Chung, and Hyeon-Jeong Suk. Awakening effects of blue-enriched morning light exposure on university students' physiological and subjective responses. *Scientific reports*, 9(1):345, 2019.

[137] Albert Mehrabian and Eric O'reilly. Analysis of personality measures in terms of basic dimensions of temperament. *Journal of Personality and Social Psychology*, 38(3):492, 1980.

[138] Michael Braun, Simon Weiser, Bastian Pfleging, and Florian Alt. A comparison of emotion elicitation methods for affective driving studies. In *Adjunct Proceedings of the 10th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, pages 77–81, 2018.

[139] John Zimmerman and Jodi Forlizzi. Research through design in hci. In *Ways of Knowing in HCI*, pages 167–189. Springer, 2014.

[140] Patrick W Jordan and Alastair S Macdonald. Pleasure and product semantics. *Contemporary ergonomics*, pages 264–268, 1998.

[141] Bruce Hanington. Methods in the making: A perspective on the state of human research in design. *Design issues*, 19(4):9–18, 2003.

[142] Bettina Laugwitz, Theo Held, and Martin Schrepp. Construction and evaluation of a user experience questionnaire. In *HCI and Usability for Education and Work: 4th Symposium of the Workgroup Human-Computer Interaction and Usability Engineering of the Austrian Computer Society, USAB 2008, Graz, Austria, November 20-21, 2008. Proceedings 4*, pages 63–76. Springer, 2008.

[143] Rachael E Jack. Culture and facial expressions of emotion. *Visual Cognition*, 21(9-10):1248–1286, 2013.

[144] Rachael E Jack, Oliver GB Garrod, Hui Yu, Roberto Caldara, and Philippe G Schyns. Facial expressions of emotion are not culturally universal. *Proceedings of the National Academy of Sciences*, 109(19):7241–7244, 2012.

[145] Bill N Schilit and Marvin M Theimer. Disseminating active map information to mobile hosts. *IEEE network*, 8(5):22–32, 1994.

[146] DE Hogg, GH Macdonald, RG Conway, and CM Wade. Synthesis of brightness distribution in radio sources. *Astronomical Journal, Vol. 74, p. 1206-1213 (1969)*, 74:1206–1213, 1969.

[147] James A Russell and Albert Mehrabian. Distinguishing anger and anxiety in terms of emotional response factors. *Journal of consulting and clinical psychology*, 42(1):79, 1974.

[148] Hiroki Noguchi and Toshihiko Sakaguchi. Effect of illuminance and color temperature on lowering of physiological activity. *Applied human science*, 18(4):117–123, 1999.

[149] Sarah Theres Völkel, Julia Graefe, Ramona Schödel, Renate Häuslschmid, Clemens Stachl, Quay Au, and Heinrich Hussmann. I drive my car and my states drive me: Visualizing driver's emotional and physical states. In *Adjunct Proceedings of the 10th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, pages 198–203, 2018.

[150] Erion Çano and Maurizio Morisio. Characterization of public datasets for recommender systems. In *2015 IEEE 1st International Forum on Research and Technologies for Society and Industry Leveraging a better tomorrow (RTSI)*, pages 249–257. IEEE, 2015.

A

User Study scripts

A.1 Greetings: 5 minutes from the entrance to the VR room

"Explanation about the study, context - 5 min Thanks for joining us today! This user study aims to explore new leisure experiences that could be offered in future Polestar cars while you commute."

A.2 Introduction

The oral introduction is listed below. "The study will take about 45 mins to 1 hour in total and involves a VR car simulator experience, where we will explain everything about the Commuting Therapy experience, after that, we will have two assessment instruments to fill, and a short interview.

The aim of the VR simulator is to help you understand the commuting therapy experiences. We are particularly interested in how you feel about the concept itself, so it may require simple cognitive understanding of different functionalities.

Although the VR experience itself may not be relaxing, we invite you to imagine how relaxing it will be in a real scenario by paying attention to any potential sensations in your body and any thoughts in your mind.

Here's how the procedure will go: What happens before you open the APP: The experience in this user study is mainly delivered through an app. However, there's much more going on behind the APP. So, I will explain a little bit about what happens before you open the APP first.

VR Experience: Then, you'll step into the VR simulator. You'll have a few minutes to get comfortable with the virtual environment.

Main Experience: Once you are ready, the main part will begin, which will take 5 minutes. You'll experience visuals, sounds, Smells and tactile sensations. While being in this part, try to imagine every function you see in the VR is happening automatically around you during your commute.

Assessment instrument: After the VR experience, you can ask me some questions about the experience to understand the concept better. Then, we will do an emotional evaluation through PrEmo and a short questionnaire based on your experience, which I will explain later.

Discussion: Finally, we'll have a brief conversation where I'll ask you some questions about your experience. During the discussion, the audio will be recorded. Your comfort is our priority. If you feel uncomfortable at any point, please let me know immediately. You have complete control over your participation. You can choose to stop the study at any time, and you can request to have your data withdrawn from the study as well.

Yeah, That is all."

A.3 Consent form

Consent form (3 min) *"Here is the consent form. You can take as long as you want to read this, and feel free to ask me any questions at any time."*

A.4 VR Experiences

A.4.1 What happens before opening the APP

Many studies have proved that different colors and intensities of light create different psychological feelings, and light can also affect the body's biological clock, particularly by regulating melatonin production. Blue light, for example, suppresses the production of melatonin, making people feel more awake and alert.

When you are seated in the car, the car system starts reading your emotional states through facial expression analysis and hand wheel sensors. After assessing your emotional valence and arousal, the car system will recommend a corresponding mode to regulate your emotional state through different sensations. It is up to you whether you use this mode or change to another mode.

What is noticeable during the VR experience is that all the sensorial settings in the real situation will be configured in advance. Due to some technical problems, the resolution on the screen is not super clear.

A.4.2 Get started on VR Similator

Let us get started on VR sets. Do you feel that you are sitting in the driver's position? You can adjust your car seat to the position you feel most comfortable *watching the screen. Can you read the text on the screen?*

A.4.3 Ask me Questions

Are there any questions you want to ask me? For instance, some features/details in the concept that you do not understand? Or anything you are curious about?

A.4.4 Assessment instruments

A.4.4.1 PrEmo under four sensations

"As you have experienced in the VR, Commuting Therapy we are proposing is a multisensory experience. Here, we invite you to reminisce about previous experiences, and in particular we want to know what emotions the different sensory experiences evoked in you! You can use different emos here to express your emotions, and you can write down your feelings and anything you want to say briefly on sticky notes."

A.4.4.2 Overall Experience Assessment: User experience questionnaire

"Give different language version according to nationalities." Explain the rules *"Use this time to look at PrEmo, and try to form questions based on the results."*

A.5 Interview

Semi-structured interviews were conducted to gain qualitative insights into participants' experiences with the in-car system. The interviews were designed to explore various dimensions of pleasure and user experience, focusing on three main areas: Ideo-pleasure, Socio-pleasure, and Physio-pleasure.

A.5.1 Physio-Pleasure

Questions in this category aimed to capture participants' sensory experiences and impressions. Examples of questions included:

- Is there any specific sensation or feature that particularly stands out to you in the current design? Can you describe what made it memorable?
- Do you have suggestions for improving the current sensory experience? For instance, are there any aspects that you found unreasonable or uncomfortable? What changes would enhance the sensory experience?
- In your opinion, what additional sensations or features would you like to see incorporated in future designs? How could these new elements improve your overall experience?

A.5.2 Ideo-Pleasure

To assess how well the product aligns with users' values and aesthetic preferences, the following questions were posed:

- How do you feel about the visual elements of the product incorporating a narrative, such as the Nebula in the universe? Does this design make you feel more connected to the Polestar brand? Why or why not?

- Does the current design and aesthetic appeal to you? Do you experience any visual pleasure or satisfaction from the product's appearance?

- How well do you think the design reflects your personal aesthetics and values? Does it enhance your sense of satisfaction and self-fulfillment?

A.5.3 Socio-Pleasure

This section focused on how the product affects social interactions and the user's social standing. Questions included:

- If you were commuting with others, do you believe that this product could influence your social status or how others perceive you? Do you feel a sense of pride or distinction when using it?

- How does the product impact your interactions with other people during commutes? Do you feel that it enhances your relationships or communication with fellow passengers?

- For drivers and passengers, do you think the experience provided by this product would lead to different interactions or dynamics? If so, how?

A.5.4 General Experience

Finally, general reflections on the overall experience were solicited to provide a comprehensive view of participants' perceptions:

- Are there any additional thoughts or feedback you would like to share about the overall experience with the in-car system?

- Were there any aspects of the product or experience that you found particularly effective or ineffective? How could the overall experience be improved?

B

Consent Form for Participation in Commuting Therapy

Polestar is undertaking a Commuting Therapy project to explore new leisure experiences that could be offered in the future Polestar cars. You are invited to participate in a research study conducted by Xiaonan Lu from Chalmers University Of Technology. We are asking you to help with this study, by VR experience simulator, assessment instrument and semi-structured interviews, letting us analyze information about your experiences in the Commuting Therapy project. How will my information be used? The information that you provide about your experiences will be used to gain insights into leisure experiences that are promising for future Polestar cars.

The research partnership, Chalmers University Of Technology, is undertaking this user study together. This means that it will be necessary for Chalmers to share information about you and your experience of this user study. The information you provide us will be recorded and stored securely. We understand that some information may be sensitive and we will keep your information confidential and use it only for the Commuting Therapy project.

Consent I have read the information above and have had an opportunity to ask questions about the Commuting Therapy study and how my information will be used. I understand the purpose of this study and what my participation involves.

I agree to take part in the user study described above and for the information I provide to be shared with the Chalmers and this in turn allows it to share information about me and my experiences for the purpose of this user study.

I consent to participate in the user study described above and agree that the information I provide may be shared with Chalmers. I acknowledge that Chalmers may share information about me and my experiences for the purposes of this study. I understand that anonymized information about me may be included in the thesis report, which may be published online. I also understand that material from this project may be used and distributed for training and User Experience Design and development purposes. I know that my participation is voluntary and that I can choose to withdraw from the research at any point.

Contact Information If you have any questions or concerns about this study or your participation, please contact Xiaonan Lu at xiaonanl@chalmers.se

Statement of Consent By signing below, you indicate that you have read and understood the information provided above, that you voluntarily agree to participate in this study. Participant's Name (printed) Participant's Signature Date Researcher's Name (printed) Researcher's Signature Date

C

Guide for Expert Interview

We used different guidelines for interviewees with different perspective. We put the guide for engineering team here as anexample.

C.1 Guideline for Engineering Expert Interview

This is a session for XX to meet the master students and for the students to ask questions about Polestar, for example, what is Polestar Design, what we do and don't, past-present-future, expert opinions on diverse topics, perception of our own brand, competitors, trends, market, etc. The students will bring their questions to make sure they collect all the necessary information for their projects before the ideation starts.

C.1.1 Opening and Ice-breaking

Greetings:General Introduction of both sides Recording

- What are your main expertises (background)? What do you do in Polestar?
- What are you working on these days?

C.1.2 Main parts

List of available questions based on the flow of the interview.

C.1.2.1 Project Specific

- Can you tell me about a recent project you've worked on at Polestar that you found particularly interesting or innovative?
- What project(s) in the past have you done that you feel proud about?
- How does the Engineering team work? Can you walk us through the process?

- Can you go through the details of the project? (only if it sounds interesting to you).
- Why was it decided to be implemented in a Polestar car? How were the decisions made?
- How do you make decisions when developing certain built-in technologies? What constraints do you consider?
- How do you make balance between different factors (different teams, needs, stakeholders)

C.1.2.2 Built in technologies

- Can you tell us about built-in technologies in Polestar cars? What do you think the coolest technology is, among all?
- How are they being used (asking use scenarios/cases) Can you think of other use cases with these technologies?
- What technologies that competitors are offering you think is cool?
- What technology shows the core value of Polestar? (if there's any).
- What are the trends for built-in technologies these days? Are there any built-in technologies that are decided to be included in the near-future?
- What are the trends for built-in technologies these days? Are there any built-in technologies that are decided to be included in the near-future?

C.1.2.3 Core Value of Polestar

- What are the core values of Polestar (What strategic direction should Polestar prioritize in terms of its core values?)
- What does "Polestar experience" mean?
- Where do you think Polestar is headed in 10 years?

C.1.2.4 Users

- Who do you think the main (target) user or buyer of Polestar cars are?

C.1.2.5 Leisure Experiences

- What are your thoughts on in-car leisure experiences in general?
- What do you think about Polestar's in-car leisure experiences?

- Are there any leisure experiences that you wish Polestar to include in the future?

C.1.2.6 Wellness or Wellbeing Specific

- What do you think about wellness/wellbeing features being in cars these days (as technologies like smart cabin, smart cockpit emerges)?

- What features in Polestar cars do you think that promote users wellness (if any)? In your opinion, are these features relevant? why?

- What wellbeing/wellness features or concepts would you suggest for Polestar based on your expertise? Why?

- Looking ahead of smart cabins and cockpits with biometric sensing and monitoring technologies, what innovative wellness and wellbeing features do you envision Polestar implementing in its future vehicle models?

C.1.2.7 Trends

- From your perspective, what trends or technologies do you see coming?

- What do you think would be the most relevant/ bring the highest value to Polestar cars? (if several) Among those, what do you think Polestar should focus on?

- What emerging trends or technologies do you think will have the biggest impact on electric vehicles in the near future?

C.1.2.8 Future Polestar cars

- Are there any things you think Polestar should be doing but aren't at the moment?

- With the growing integration of AI and autonomous features in vehicles, how do you envision these advancements impacting the user experience within Polestar cars?

- In an ideal scenario, how do you envision Polestar cars evolving in terms of design and features over the next decade?

- In a realistic scenario, how do you envision Polestar cars evolving in terms of design and features over the next decade?

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