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Nudges-Based Design Method for Adaptive HMI to Improve Driving Safety

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Abstract: This study introduces a new operational tool based on the AEIOU observational framework to support the design of adaptive human machine interfaces (HMIs) that aim to modify people's behavior and support people's choices, to improve safety using emotional regulation techniques, through the management of environmental characteristics (e.g., temperature and illumination), according to an approach based on the nudging concept within a design thinking process. The proposed approach focuses on research in the field of behavioral psychology that has studied the correlations between human emotions and driving behavior, pushing towards the elicitation of those emotions judged to be most suitable for safe driving. The main objective is to support the ideation of scenarios and/or design features for adaptive HMIs to implement a nudging strategy to increase driving safety. At the end, the results from a collaborative workshop, organized as a case study to collect concept ideas in the context of sports cars, will be shown and evaluated to highlight the validity of the proposed methodology, but also the limitations due to the requirement of prototypes to evaluate the actual effectiveness of the presented nudging strategies.

Keywords: nudge; adaptive HMI; automotive; affective computing; driving safety; emotion regulation

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1. Introduction

People constantly make decisions, whether consciously or not (for example, they decide whether to obey a speed limit or listen to a song suggested by an audio streaming service). However, even if the responsibility for the choice rests with the user, it is evident that the characteristics of the environment in which decisions are made, as well as the type of information provided and how it is provided, can strongly influence people's choices and "nudge" their behavior in particular directions.

According to Thaler and Sunstein [1], "a nudge is any aspect of choice architecture that alters people's behavior in a predictable way without prohibiting any options or significantly altering economic consequences." Generally, nudges are effective because people do not always act rationally. In particular, research in psychology has shown that, owing to cognitive limitations, people act in a rationally limited way, with the influence of heuristics and cognitive biases in decision-making [2]. For example, several environmental factors can arouse emotions and bias human choices. Human emotions can play an important role in the decision-making process, as they can strongly affect a person's attention and impact choices. For example, during driving tasks, driver behavior can vary significantly based on their emotional state [3], and it is well-established that aggressive driving due to the inability to manage one's emotions is a cause of accidents [4,5]. Furthermore, negative emotions such as anger, frustration, anxiety, fear, and stress can alter perception and decision-making, leading to the misinterpretation of events and even affecting physical capabilities [6,7]. Indeed, the causal relationship between risky behaviors of drivers with high levels of aggressiveness or stress and road accidents and mobility problems is well known [8].

One way to improve driving safety and comfort is to modify several environmental factors that may arouse emotions. For example, by playing sad music, it is possible to positively influence driving attention and promote safer driving behaviors [3].

In this context, this study proposes a design thinking-based approach, following the Stanford Hasso-Plattner Institute of Design version [9], to support the design of adaptive human machine interfaces (HMIs) that aim to modify people's behavior and support people's choices, to improve safety using emotional regulation techniques through the management of environmental characteristics (e.g., temperature and illumination), according to an approach based on the nudging concept.

The main objective is to support the ideation of scenarios and/or design features for adaptive HMIs to implement a nudging strategy associated with the elicitation of an emotional state to increase driving safety. To this end, we introduced an operational method based on the observational tool AEIOU [10]. The proposed methodology, however, is general enough to be applied not only in this context, but also whenever there is a desire to innovate a product through the introduction of AI-based ICT technologies, in order to make products more adaptive and responsive to user needs. The proposed ideation process was exemplified through a case study related to the automotive context.

2. Nudges and Emotion Regulation

The nudge theory states that humans are prone to making mistakes [11]. These mistakes stem from rules of thumb, heuristics, and cognitive biases, which are used as shortcuts to reduce the amount of information required for decision-making processes. However, heuristic thinking can help with decision-making, it can also limit and alter thinking because it is instinctive, irrational, and emotionally impacted [2]. Emotion- and affective-based thinking are particularly crucial in situations where time pressures the person to make a deliberate action [12], such as driving. Therefore, as with many daily life decisions, emotions have a significant impact in the driving context, with affective heuristics being one of the biases that rely on emotions when estimating risks and benefits in vehicles.

Many studies have shown that emotional states influence driving performance [13], reaction times [14], and perceived potential risks and distractions negatively [15], causing drivers to engage in more risks [16] and other driving behaviors that could potentially lead to major safety issues during driving, such as aggressive driving [17]. Aggressive driving is particularly important as it is a voluntary driving behavior as opposed to other involuntary risky driving behaviors caused by increased workload due to negative emotional states [17]. This indicates that emotions influence driving behavior by increasing the workload and negative emotions can lead to voluntary unsafe driving behavior. Thus, it is proven that emotions shape intentions, decisions, and actions.

Therefore, in many situations, influencing people's emotions affects their decisions, intentions, and subsequent actions [18]. Therefore, nudges rely on heuristics, in this case, affective heuristics and emotions, to influence decisions [19] in vehicles.

Nudge theory claims that choices presented to people influence their decisions, as choice architecture is unavoidable [1]. Therefore, a well-designed choice architecture should have the ability to allow users to select their options that considerably benefit them [10]. According to Thaler et al. (2012), choice architecture designs an environment in which people make decisions. Therefore, the job of the choice architect is to provide an environment in which the elements encourage users to make decisions that are in their best interests. In the driving context, the frame of the choice architecture may be drawn as the interior elements of the vehicle, such as lighting, temperature, and infotainment features. These interior elements comprehend the HMI components that the driver interacts with directly by manipulating or being influenced by them. By contrast, considering that emotions are temporary, the choice architecture of an HMI should be designed with the ability to suit various emotions and accompanying decisions. Consequently, an HMI should have the ability to adapt to different contexts in which users experience different emotions and various emotion-influenced behaviors and decisions, which could have negative consequences, such as road accidents.

Adaptive HMIs should detect emotions, determine appropriate nudging strategies to detect emotions, and adapt to an optimized driving/emotional state. Since the beginning of the 2000s, adaptive HMIs to regulate emotions and optimize driving behavior to ensure safety have been a topic of interest [20].

2.1. Music

Music is one of the most researched techniques that has been demonstrated to regulate driver emotions in various ways. First, some studies have shown that the valence of music is an important factor, where sad music leads to calmer driving behaviors compared to listening to happy music. Conversely, happy music decreases the driving performance of drivers [2]. This means that the valence of music is important when designing an HMI architecture, particularly considering that "happy" music is usually the default option. Therefore, in situations in which anger is detected, instead of leaving the default choice to the driver and keeping the music "happy," the strategy of creating a choice architecture with calmer music as the default should benefit an angry driver. Second, calming music not only improves driving performance, but also increases the positive affectivity of drivers [21]. Hence, calming music has the dual effect of regulating both negative emotions and driving performance caused by these negative states. Finally, it was also observed that the ability of angry drivers to select their music may reinforce aggressive driving behavior [22]. When angry people select music, they tend to drive more aggressively by accelerating and braking in a more aggressive manner. By contrast, when they were forced to listen to happy or sad music, it helped them reduce this behavior to the level of neutral emotional drivers [21]. Further evidence on the effects of music and different music genres on driving style is also investigated in [23,24]. These results indicate that when angry drivers select their own music, they might drive more aggressively compared to when they are forced to listen to calmer music that is not their choice. An indication of these results is to design an adaptive HMI that can calm down the angry driver and also alter the behavior by changing the self-selected music to calming music.

2.2. Ambient Lighting

Lighting is a salient interior feature that is employed in adaptive HMIs. As a part of the choice architecture, some studies have shown that blue light can be used as a cue to increase relaxation when the person is in an angry state. Both physiological data and self-measures indicate that feelings of anger subsided with blue light [25]. In addition to blue light, orange was found to be crucial when drivers were angry. A study showed that both blue and orange ambient light improved the lane-keeping of angry drivers compared to the no-lighting condition [26]. Therefore, overall ambient lighting is an important element of adaptive HMIs; however, color choice should be investigated further to determine ideal color matching to emotions.

2.3. Temperature

Increased heat sensations can be accompanied by intense emotional states. One way to nudge these emotions is to benefit from air ventilation systems to regulate bodily reactions and eventually emotions. Not only intensely aroused states, but also under-aroused states, such as fatigue, can benefit from temperature adaptation. It was observed that using cool air to increase alertness resulted in better driving, as cooling activated the sympathetic nervous system [27].

2.4. In-Vehicle Vocal Assistants

In recent years, in-vehicle voice assistants have been included in HMI design. Moreover, voice assistants that can track and adapt to driver behaviors and emotions are considered driving companions [28] rather than solely voice input channels. Therefore, conversational voice assistants are important components of adaptive HMI designs that regulate driver emotions and behavior.

2.4.1. Adaptive Voice Messages

The potential perks of matching the emotional valence of the voice assistant to the driver's emotion have been under investigation for over 15 years and have shown promising results [29]. This indicates that a voice assistant should be able to detect the driver's emotions correctly and respond to the driver with the appropriate emotion. It has been demonstrated that angry speech outputs from the voice assistant increase alertness and reduce distraction in under-aroused states [30].

Voice messages and interactions may require additional cognitive resources that can increase the existing workload caused by negative emotional states and lead to distraction. Therefore, increased workload due to negative emotional states, such as stress, should be considered when designing interactions [31]. For example, in such low-arousal states, voice assistants can interact more frequently in a manner that aims to arouse an emotional state for optimal conditions, in addition to matching the valence of the voice output.

2.4.2. Reframing Events

Another nudging strategy is to gently reframe an experienced negative event in a positive way, thus indirectly affecting emotional states. One study demonstrated that when a voice assistant reappraised a frustrating event, the driver's interpretation of that specific situation changed to a positive perspective. Moreover, this reframing causes drivers to experience fewer negative emotions after reappraisal and leads to better driving performance [32].

2.4.3. Warning/Feedback

Providing feedback to actions is the most effective method to help people improve their performance; hence, a well-structured architecture will inform people when they engage in mistakes or when they are performing well [9]. Visual or acoustic feedback is extensively used in HMI designs. However, considering that visual notifications require attention and a diversion of the gaze from the road to the visual feedback source, involving voice assistants in feedback designs while focusing on the workload and necessity of a given emotion, can be a promising candidate to use feedback nudges. This can be observed in the design of recent emotionally adaptive voice alert systems, in which alerts are adaptive to the driver's emotions. For example, when positive emotions are detected, voice alerts are conveyed more moderately compared with negative emotions, when voice alerts are delivered in a more intense manner [33]. Therefore, not only is matching the valence of the voice assistant important, but the frequency and intensity of the feedback provided by the feedback system could also be a part of the in-vehicle nudging strategies to ensure safe driving behavior.

Feedback channels are not only limited to visual and acoustic/speech, but a recent study has shown that olfactory feedback could also be a part of the choice architecture. According to the results of the study, fewer mistakes were made when participants received olfactory notifications rather than visual feedback. In addition, olfactory feedback was found to be more helpful and less distracting than visual feedback, and participants preferred it [34].

2.5. User Interfaces

User interfaces, as well as other HMI elements, are important for influencing emotions both negatively and positively. Some of these features can trigger negative emotions, such as in navigation systems [35]. Navigation is one of the most commonly used features of an infotainment system. Therefore, it can be utilized as a tool to regulate emotions as the route has an impact on the driving experience. Some studies have suggested developing navigation systems that can calculate routes to enhance the driving experience. For example, drivers positively rate leading the route to a sunset or passing the route through a beautiful landscape. User surveys show that drivers seek not only the fastest route but also experience-enhancing factors [36]. Overall, surveys have also demonstrated that people experiencing negative situations ask for better information management and higher degrees of automation [37]. Proposing routes that can provide an enjoyable experience could benefit from this architecture. In addition to navigation, higher automation is necessary for drivers to enhance their driving experience in negative situations.

In vehicles, emotion regulation using nudges is necessary to ensure less risky driving behaviors and distractions. One way to gently push drivers that are not in optimal driving states is to use adaptive HMIs to establish a new choice architecture with default options based on the detected emotion of the driver. Thus, adaptation ensures the fit of the choice architecture to various contexts and emotional states. In addition to choices, feedback could be provided with a multimodal approach in which visual, acoustic, olfactory, or any other potential channel is matched individually or combined to the necessities of the driver state and the situation.

In this study, it is believed that effective emotion modulation strategies embodied within a vehicle's HMI can be provided in the form of nudges, as defined by Thaler and Sunstein [1]. These authors introduced the notion of nudging to suggest that our knowledge about those systematic biases in decision-making can be leveraged to support people in making optimal decisions.

In this way, they can provide answers to the potential bias caused by a potentially negative emotional state when driving. For example, if a state of anger contributes to reducing the perception of risk, it is inferred that ambient lighting by changing the chromatic atmosphere of the vehicle can transform a negative emotion into a neutral or even positive state. The transformation of this chromatic environment can be considered a nudge in support of emotional modulation. To achieve this, in addition to technology for emotion detection, detailed empirical evidence of emotion-induced perceptual changes and experience with nudges that facilitate this transformation are required.

These elements are the foundation for the methodology, detailed as follows: starting from these basic elements, the designers involved in the design process will be able to provide more detailed nudging solutions that are better suited to the use cases and more effective than the design. Furthermore, for nudges to act as emotional modulators, on-board HMIs need to be adaptive, which means they need to be able to transform an interaction element, for example, the vehicle's color environment, from one condition to another dynamically and according to an emotional state.

3. AEIOU Observational Framework

AEIOU is one of the most widely used ethnographic methods [38]. It has the advantage of allowing the user experience to be analyzed with a high level of detail [39] and enabling the identification of factors that influence the user experience from a holistic point of view. In addition, the heuristics on which it is based are easy for designers to understand and remember; thus, it is a particularly useful tool for the discovery process.

AEIOU, in the version adapted by Wasson [39], is characterized by five components (or heuristics): activities (A), environment (E), interactions (I), objects (O), and users (U). Activities are what people perform to achieve their goals. The environment is where the activities occur. The environment is defined as both the surroundings with which the user interacts and within which the activities occur, as well as the users' inner conditions, such as emotions/states of mind, which may influence how the user approaches the actions/activities. Interactions are the activities of building blocks, and therefore represent the set of tasks (or microtasks) that the user can perform to achieve their goals through an interaction with various products or services. These objects represent various devices or technologies with which the user interacts. Finally, users represent people who model their preferences and actions to achieve their goals.

AEIOU provides a useful model for collecting qualitative contextual information. Moreover, its worksheet is divided into five domains of interest and can be organized as a simple note-taking document in each section or with columns similar to a spreadsheet.

4. AEIOU as a Tool to Support the Designing of Adaptive HMI to Nudge Safe Driving Behavior through Emotion Regulation

A new AEIOU-based operational tool within the design thinking process, which may provide support for designing experiential scenarios employing nudging strategies, has been defined.

To this end, as a first step, a study was conducted to reconsider AEIOU, leading to a revision of this tool.

Therefore, the new tool that was defined while maintaining the structure of the original tool and is based on five categories or heuristics (i.e., activities, environments, interactions, objects, and users), presents a partial revision of the various considered elements. In particular, the new AEIOU tool aims to define possible experiential scenarios, starting from the definition of a specific user (persona) and a specific goal.

The defined workspace can be divided into the following five components:

A Activities: What does the end user (defined through personas) perform to achieve the set goal? Activities must be defined as atomic units; therefore, they cannot be further broken down into sub-activities. In a scenario where the user's goal is to "drive safely", the activities will, for example, be about getting into the car, buckling up, starting the car, leaving the parking lot, tuning in to the preferred radio station, etc.

E Environments and emotions: Possible events that the user may have to handle, or environments (or contexts) in which the user must act to achieve the goal, or environmental characteristics that may influence the user's behavior during the described activities, which may alter the emotional state. Examples of possible environments (in the case of the safe driving objective) can be a city street or country road. Examples of the events or environmental characteristics that can influence the performance of the activity and the emotional state include a sudden rainstorm or a tire that suddenly becomes flat. Each event, environment, or environmental feature may be associated with one or more emotions. The emotions indicated aim to detect the emotional state of the user at the time the event occurs, and therefore must be directly associated with the event/environmental factor and not with its long-term effects. For example, in the case of a puncture, it can be assumed that the user may be surprised, angry, or afraid, whereas the sadness may occur later because of the thought of economic damage should not be considered. To facilitate the definition of possible emotional states, the use of emojis has been proposed (Figure 1).

I Interaction/cards: These define behavioral factors that have the potential to influence user perceptions based on emotions. To derive nudges that can influence our perceptions according to emotions, the following basic factors were identified from the research background:

- We perceive the climbs to be steeper when we are sad than when we are happy;
- Emotion enhances perception and discrimination; when we experience negative emotions such as fear, contrast sensitivity is improved;
- Negative emotions decrease our attention to details (e.g., the tree);
- Positive emotions push us toward the big picture (e.g., the forest);
- When feeling positive emotions, people tend to use stereotypes and other categorical information, whereas when emotions are negative, people focus on behavioral or other detailed information rather than using broad categories.
- Anxiety increases sensitivity to potential threats, whereas positive emotions increase sensitivity to rewards.

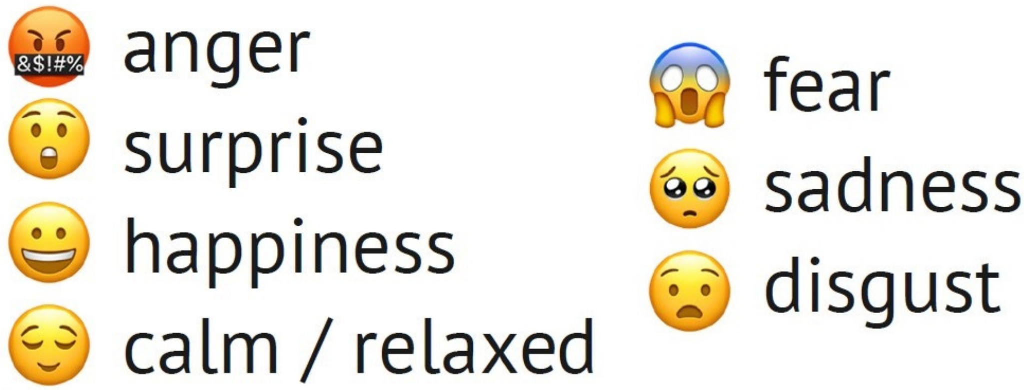

Figure 1. The emoji used to define the user's moods associated with the Environment sticky notes.

To facilitate designers in defining proper nudges, several cards were created as described below. They aim to facilitate the creation of concrete design solutions capable of performing emotional modulation. Each card consists of the following:

- A title indicating the macro-theme related to emotion regulation, for example, rewards and treats.
- A symbolic image showing the alternatives induced by the different emotions is constructed in such a way that it is sufficiently generic and symbolic to guide but not constrain the designer.
- A short sentence describing the rationale for relating perceived elements and emotions. For example, positive emotion enhances detection of rewards, whereas anxiety facilitates threat detection" (Figure 2).

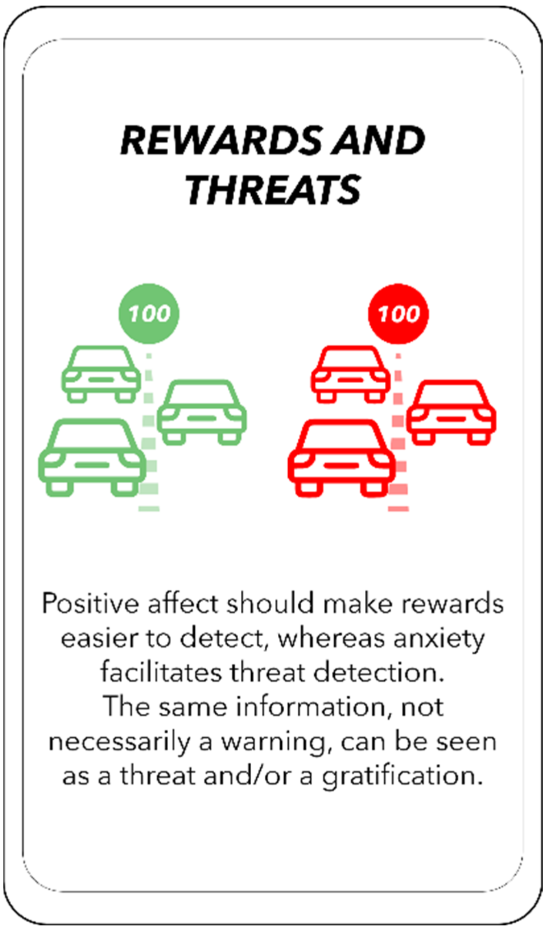

Figure 2. Example of cards structure.

O Objects: This includes all the elements that are part of the environment in which the user will interact. They also include superpowers: technologies and systems that can be used to implement emotion regulation actions to implement specific nudge strategies.

U Humans: The original AEIOU tool considers users, but in this case, because it was decided to focus the analysis on a specific user (Persona), this scope was redundant. Consequently, in this domain, it has been decided to consider other people with whom the user may interact during his experience and who may influence the user's behavior, supporting or opposing him in achieving the goal (such as a traffic policeman, a passenger, or another driver).

The AEIOU framework was constructed through workshop activities characterized by two main phases.

The first phase is a part of the empathize and define steps of the design thinking process and consists of preparatory activities for the actual workshop. In this phase, the team synthesizes available information about the user and the context of the interaction, distilling what they have observed and learned into insights. The outcome of this activity is as follows:

- The definition of personas that represents the profile of the target users.
- The definition of a use case scenario.
- The definition of specific goals for each persona.
- Possible behavioral factors that can support or counteract the achievement of a goal (cards).
- Technologies and tools (superpowers) that can be used to implement the identified nudge strategies.

The second phase is within the third ideate step of design thinking and involves actual workshop activities in which a multidisciplinary team of at least six people, including a moderator, is involved. These activities led to the definition of the possible experiential scenarios. The workshop activity must focus on one identified person at a time, and is characterized by three main steps:

1. Collaborative production of sticky notes: Each participant must contribute to populating the starting board by defining possible activities, events/emotions, objects, and other individuals (humans) that can affect the achievement of the goal by the user (persona) through post-it notes. Moreover, they analyzed previously defined cards that describe the behavioral factors contributing to the achievement of the goal. At the end of this phase, the board is populated with all the "ingredients" useful for the subsequent definition of the scenarios.
2. Production of ideas: In this phase, the participants must attempt to combine the various components identified (the "ingredients" previously defined) and create real stories and concept ideas. Each element that characterizes a particular experience/scenario will then be connected to the others to identify a particular flow that can visually represent the story through various columns (Figure 3).
3. Evaluation of ideas: Each participant describes their ideas and proposes a short description of them. At this point, a voting phase occurs in which each participant has a small number of preferences to assign (usually three) in the form of "sticky dots". At the end of this collaborative evaluation phase, ideas with the highest votes are considered for the prototype phase. The purpose of this activity is mainly to bring out the needs that are perceived as the most important by the majority of the group, leaving aside those that may be considered more "accessory".

Once defined, solution ideas must be concretized and implemented into design concepts. This involves the design of the overall adaptive user interface functions and the definition of adaptation rules and their formalization into an adaptation management system [40,41].

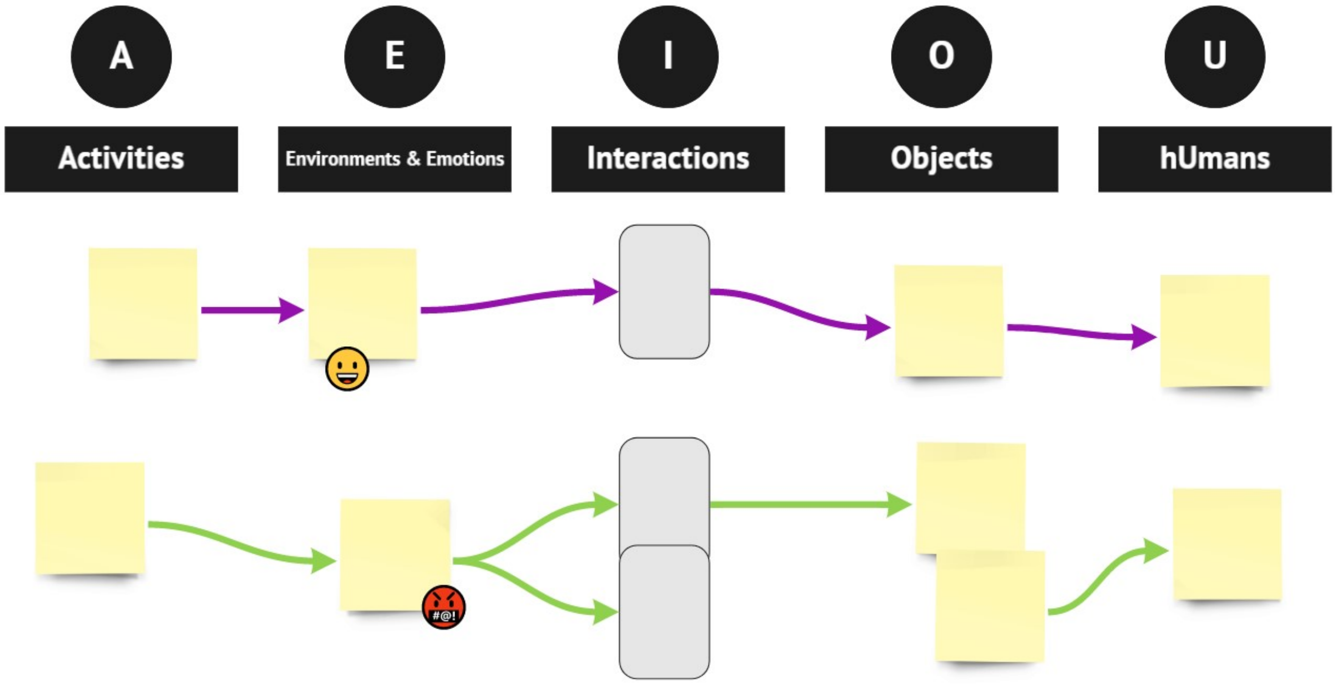

Figure 3. Two user flows for the definition of a story/idea.

5. Case Study

The case study described in this section shows how the proposed approach, based on the design thinking methodology and the AEIOU observational method, can be applied to design scenarios and/or design features for the solicitation of an emotional state to increase driving safety.

The problems, needs, and expectations of typical users were first outlined as required in the first empathize phase of the design thinking methodology. To this end, user and context analyses were previously conducted using various ethnographic methods. Then, Personas and use scenarios were defined following the first phase of the proposed approach, including the preparatory activities for the workshops, based on the collected information. In the same activity, following the define phase of the design thinking methodology, the specific goals for each persona and the heuristics that can influence the user's behavior to adopt the best nudging strategy were identified; the output of this phase comprised the definition of the cards for the interaction phase of the customized AEIOU tool. Finally, a benchmark was applied to the technological solutions applicable to the case studies to extrapolate the superpowers necessary for the definition of the objects.

5.1. Partecipants

The activities were attended by eight people, divided into two groups (2 females and 6 males) aged between 27 and 49 (Mean = 36.5, SD = 6.78), managed by a facilitator specializing in the organization of workshops with remote collaborative tools.

All the participants had a valid driving license since at least 3 years. Among them, there were several experts: four product specialists and four customer specialists in the sports cars commercial sector.

The number of participants was limited as the proposed case study aims to simulate a design team intent on gathering requirements and collecting ideas. The choice to include mainly experts from the respective fields concerns the necessity to maximize the effectiveness of the workshop activities: the proposed methodology requires a strong expertise from the participants regarding the product context and customer characteristics and needs.

5.2. Study Design and Procedure

Workshop activities were conducted remotely using the online Miro platform. The proposed framework was applied to support two different phases of the design-thinking process, described as follows.

5.2.1. First Phase: Empathize and Define

During the workshop preparatory phase, participants must organize the definition of personas, user goals, usage scenarios, cards, and superpowers.

At the end of the first activity, two personality types (personas) emerged:

- The Superdriver, i.e., mainly young users looking for excitement.
- The collector, that is, a user who owns a sports car only for the social status, with no particular interest in the emotions felt while driving; however, certainly interested in those associated with the purchase of the car.

Considering the main goal of the activity, that is, to identify solutions able to increase the driving safety of the user following a nudging approach, the output of the first activity is further analyzed to extrapolate the specific goals for each persona, as well as the typical behaviors and heuristics that can influence them, and the available technological solutions. The results showed the possibility of automating the environment with which the user interacts (the car interior) to analyze the user's emotional mood in real time. Such information is fundamental to drive the selection and activation of proper nudging strategies with the aim of arousing more favorable users' emotional states to increase safety. In particular, it has been planned to use emotional telemetry instruments, such as cameras mounted in the cockpit and directed at the driver's face, and deep learning-based software for the recognition of Ekman's universal emotions (happiness, surprise, sadness, anger, disgust, and fear) [42,43] and the direction of gaze and head [44]. In addition, it has been considered possible to act on the car's electronic instrumentation and, in particular, on its infotainment system, thus acting on the interior lighting and music played according to the approach defined in [45], where a tool for associating different genres of music, light colors and Ekman's emotions is proposed. Hence, the superpowers, that is, the steering controls, infotainment system, voice interaction systems, ambient lights, sounds, and music, seat, etc., were defined. Several cards prepared to explicate the behavioral factors may affect a user's safe driving performance (Figure 4).

5.2.2. Second Phase: Ideate

Once all elements were available, as previously described, the workshop activity based on the application of the proposed tool could begin. In this activity, participants were given principles to adhere to, in particular, aiming for the quantity of ideas produced rather than the quality and building on the ideas of other participants. Subsequently, two groups were organized, one for each type of persona, and each participant was asked to produce a post-it note for each column of the board, referring to cards, objectives, personas, and superpowers established earlier in the preparatory phase. Then, each participant was asked to create a flow between the post-its and cards placed on the board and thus define a 'story' utilizing these elements. For each "story," the participant had the task of associating a project idea that met the objectives initially set. The results included the definition of several applicable ideas (Figure 5).

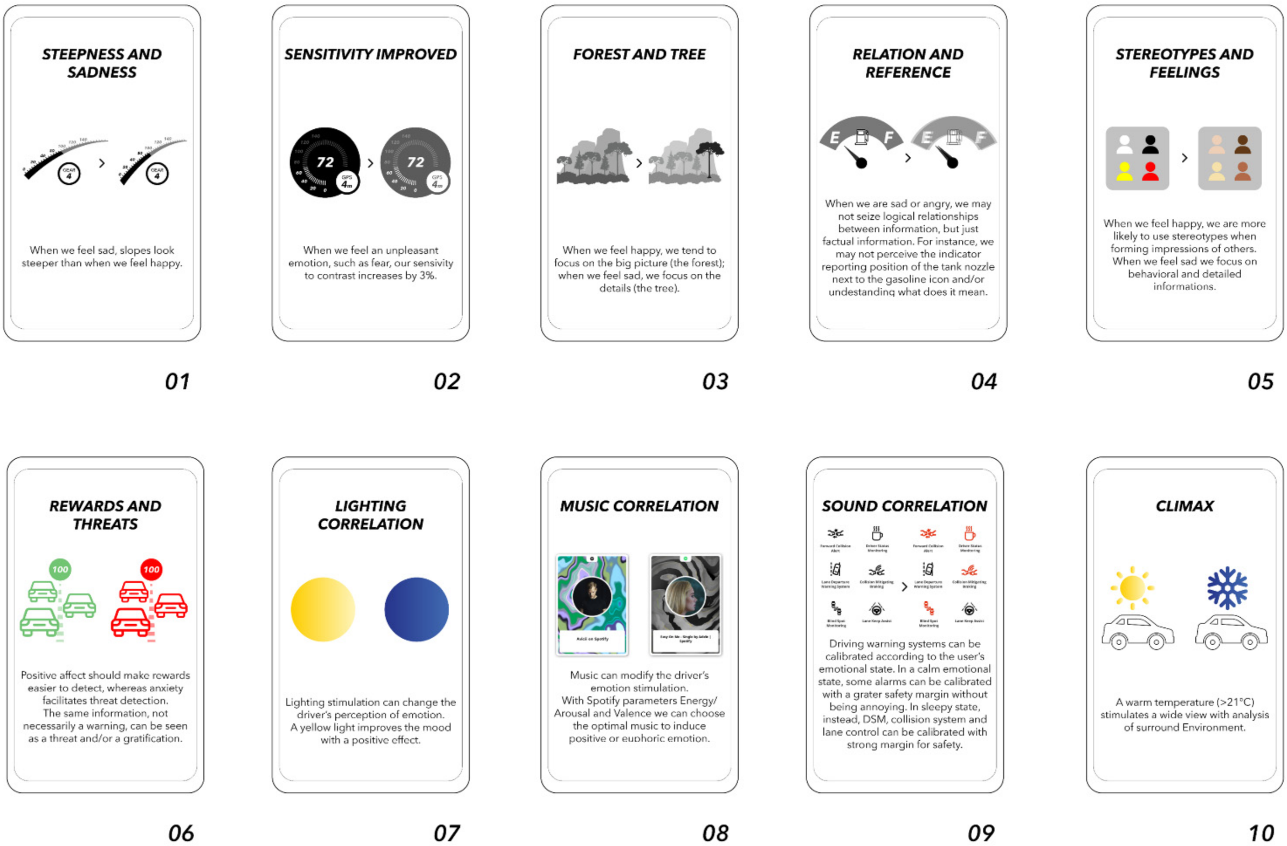

Figure 4. Cards defined for the automotive use case.

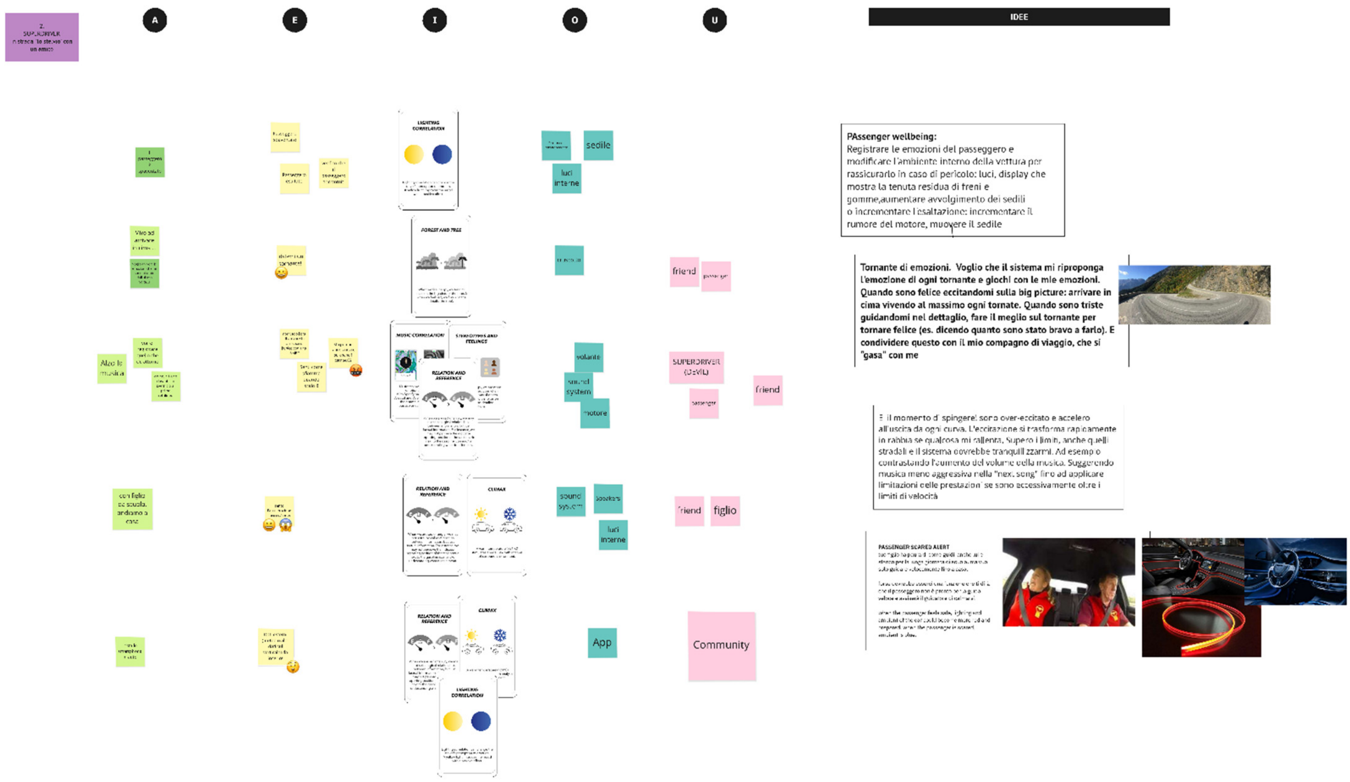

Figure 5. The conclusion of the ideation phase for the Superdriver persona.

At the end of the workshop, all participants in the two groups were asked to use their two votes to assess which of the ideas best adhered to the project objectives and technological constraints, as well as which had the best commercial appeal.

At the end of the evaluation, the two ideas with the most votes were as follows:

- Passenger wellbeing: Record the passengers' emotions and modify the car's interior environment to reassure them when they appear anxious or scared: lights, soothing music, display showing residual brake, and tire grip.
- Soft change: The user is overexcited and accelerates at every turn, feeling angry if something decelerates and starts to exceed the road limits. The system notices this altered state and attempts to calm the driver by dimming the lights, switching to colors associated with emotions with a low level of arousal, counteracting the increase in music volume, and suggesting less aggressive songs in the playlist.

5.3. Subjective Measures

After the workshop activity, participants were asked to fill out some questionnaires in order to assess the experienced creativity, the self-efficacy beliefs, and the perceived usefulness and ease of use, referring to the use of the tool to gather concept ideas in the previously defined context. The questionnaires submitted were repurposed from those proposed in [46], where a design support tool based on nudges was hypothesized. In particular, focusing on these indicators, four questionnaires were proposed: the first to detect Experienced Creativity based on the Creativity Support Index of [47], where six indices are required to be evaluated using 10-point Likert scales (i.e., Collaboration, Enjoyment, Exploration, Expressiveness, Immersion, and Results Worth Effort). In the second and third questionnaires, participants were asked to complete an adapted version of TAM's perceived usefulness and perceived ease of use scales [48], using 7-point Likert scales. In this case, the submitted assertions were: (1) I find the tool cumbersome to use; (2) Learning to interact with the tool is easy for me; (3) I find it takes a lot of effort to become skillful at using the tool; (4) Overall, I find the tool easy to use; (5) Using this tool improves the quality of the work I do; (6) Using this tool makes it easier to do my job; (7) Using this tool enhances my effectiveness on the job; and (8) Overall, I find this tool could be useful in my job. Finally, a fourth questionnaire was submitted by repurposing a modified version of the 4-item questionnaire [46] grounded on Bandura's guide for creating self-efficacy scales [49], evaluating: (1) Identification of technologies for behavior change; (2) Selection of different behavior change techniques; (3) Objectively select the best concept ideas.

At the end, participants were asked to provide generic comments to evaluate the overall experience.

6. Findings

Scores related to the "Experienced Creativity" and the considered dimensions were calculated by averaging the respective item values per participant. A graph displaying the data distribution of the considered evaluated metrics (i.e., Collaboration, Enjoyment, Exploration, Expressiveness, Immersion, and Results Worth Effort) is shown in Figure 6.

As reported, Experienced Creativity in using the proposed tool shows quite high overall values, especially the Results Worth Effort (Mdn = 8.5), demonstrating how the participants considered the experience really useful relative to time and effort. However, Immersion (i.e., how much of the participants' attention was totally absorbed while using the tool) was not rated as positively (Mdn = 6.5), probably due to the frequent interactions among participants.

Similarly, the results for Perceived Ease of Use (Cronbach's alpha = 0.82; Avg = 6.06; Std Dev = 0.75) and Usefulness (Cronbach's alpha = 0.79; Avg = 5.9; Std Dev = 0.73) were interesting. Indeed, it was found that participants considered very easy to interact with the tool, as shown by the values collected for "Overall, I find the tool easy to use" (Mdn = 6.5), although there were some difficulties in initially understanding the approach to be followed during the workshop, as reported by "Learning to interact with the tool is easy for me"

(Mdn = 5.5). Similarly, considering the sentence "Overall, I find this tool could be useful in my job" (Mdn = 5.5) for the perceived usefulness, most participants evaluated the overall activity quite useful for the concept's ideation.

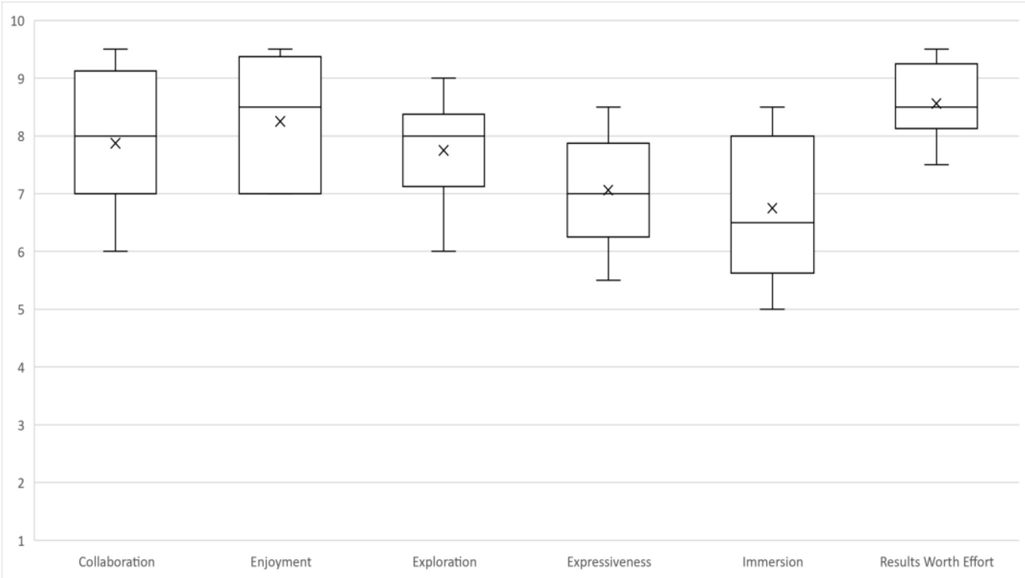

Figure 6. Participants' evaluation of Experienced Creativity.

Finally, the Self-Efficacy questionnaire (Cronbach's alpha = 0.77; Avg = 5.58; Std Dev = 0.88) showed slightly more uncertainty about the effectiveness of the instrument, but still good results.

7. Discussion and Conclusions

The results obtained from the proposed workshop enabled the realization, in a collaborative manner, involving stakeholders and technicians, of concept ideas that use the nudge concept, allowing the development of features and products with adaptive interfaces capable of responding predominantly to the problem of driving safety.

The presented case study focuses on defining new ideas to nudge a particular emotional behavior and so improve driving safety. As stated in [18], this approach could lead to ethical implications that could limit the practical applications of this type of approach.

However, the proposed tool is general enough to support the definition of nudging strategies aimed at pursuing different objectives. Although regulation of driver emotion is an important factor in nudging safe driving, it is indeed not sufficient. Other solutions are needed to encourage other virtuous behaviors (e.g., to wear seatbelts, drive sober, pay attention to the road, and take a break when tired). Similarly, although the presented case study focuses on this purpose, the proposed approach is certainly applicable in many other contexts that do not necessarily concern the automotive sector or safety problems. Another context in which this approach may find strong applicability is, for example, the entertainment.

The introduction of the proposed tool has been particularly appreciated by the experts consulted in the case study because it enabled the identification of viable solutions in a short time. However, in order to evaluate its real effectiveness, as well as to evaluate the application of the proposed technologies (e.g., how much ambient lights could affect the driver's state during the daytime), it is necessary to build prototypes of the identified nudging strategies, so that end users can also be involved in their evaluation. To this end, several high-fidelity mockups should be constructed using extended reality technology to enable testing of design solutions at a conceptual level and to collect user-interaction information necessary to refine the adaptation rules.

To enable testing and validation of the proposed solution and to collect information to support the definition and improvement of adaptation rules, the next step of the design thinking methodology requires grounding the solutions previously identified through the construction of prototypes.

Developing an adaptive HMI capable of promoting user behaviors conducive to achieving certain goals in accordance with environmental conditions based on proper nudging strategies, remains a challenging task; it requires the definition of a proper interaction model with respect to the identified scenarios. In general, the definition of an interaction model based on inferential rules requires the collection of a huge amount of information regarding the user profile, the actual user activity that should be supported, and the environment in which the interaction occurs. However, there is no possibility of direct access to the entire reality domain; therefore, the system to be developed must act within a range of uncertain data. Consequently, to define interaction models, inference and evaluation mechanisms should be learned from observational data acquired during the user-product interaction. To this end, several high-fidelity mockups should be constructed using extended reality technology to enable testing of solution ideas at a conceptual level and to collect user-interaction information necessary to refine the adaptation rules. The construction of the prototypes will have to support extensive experimentation to gather information also through the use of surveys or questionnaires, in order to determine the goodness of the different nudging strategies hypothesized on the basis of the opinion of the end-users.

In this research, the methodology has been introduced in a preliminary manner and although the case study has shown potential, it is necessary to conduct further studies with the aim of assessing the effectiveness and efficiency of the proposed method, as well as the limitations in adopting nudging strategies in the proposed context, given recent studies that would like to refute its effectiveness in behavioral change [50]. In particular, it will be necessary to conduct studies to compare the capacity of the proposed tool with the idea generation methods commonly adopted today to support conceptual design. Other studies will have to be conducted to assess the method's effectiveness in different design contexts: another limitation of the study concerns its application to niche products with a high propensity to customization. It will therefore be necessary to assess whether the methodology can also support the generation of ideas for consumer products, possibly even intangible products (e.g., software).

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