Heartbeat: Experience the Pulse of an Electric Vehicle

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ABSTRACT

Electric Vehicles (EVs) are an emerging technology and open up an exciting new space for designing in-car interfaces. This technology enhances driving experience by a strong acceleration, regenerative breaking and especially a reduced noise level. However, engine vibrations and sound transmit valuable feedback to drivers of conventional cars, e.g. signaling that the engine is running and ready to go. We address this lack of feedback with Heartbeat, a multimodal electric vehicle information system. Heartbeat communicates (1) the state of the electric drive including energy flow and (2) the energy level of the batteries in a natural and experienceable way. We enhance the underlying Experience Design process by formulating working principles derived from an experience story in order to transport its essence throughout the following design phases. This way, we support the design of a consistent experience and resolve the tension between implementation constraints (e.g., space) and the persistence of the underlying story while building prototypes and integrating them into a technical environment (e.g., a dashboard).

Author Keywords

Electric Vehicle; Experience Design; User Experience; UX

ACM Classification Keywords

H.5.2 [Information Interfaces and Presentation]: User Interfaces – *Haptic I/O, Natural language, Prototyping.*

INTRODUCTION

Electric vehicles (EVs) are clean, quiet, and sustainable. They promise a new driving experience due to a strong yet silent acceleration. Thus, we observe increased interest in politics and economy to promote EV development. Both the U.S. [37] and China [33] aim at one million EVs on their streets until 2015, and Germany is willing to reach this goal in 2020 [3]. Nevertheless, EVs seem still unattractive to potential customers: they are expensive and drivers have little confidence in the new technology.

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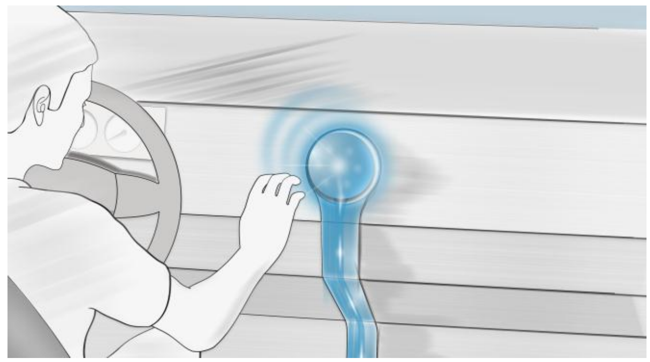

Figure 1. Heartbeat communicates the state of the electric drive and the batteries of EVs as visual and haptic feedback

In response, manufacturers need to rethink the entire car mobility concept including charging station networks, smart grids, and car sharing, but also the car's user interface including engine sound, haptic and visual feedback as well as driving behavior. This challenge, fortunately, comes with exciting new opportunities in designing assuring in-car feedback, comforting users' uncertainty of the new technology and enhancing drivers' experience in EVs.

As the research community already pointed out, Electric vehicle information systems (EVIS) [24] aim at supporting drivers' awareness about the energy and acceleration state of an electric vehicle. We contribute to this need by designing and implementing Heartbeat, a new type of EVIS providing ambient visual and haptic feedback. Heartbeat (see Figure 1) substitutes the lost pulse of the EV and informs drivers in a subtle yet comforting way of the state of the electric drive and the battery.

We report on our experience in designing and implementing Heartbeat and present design rationales at various stages of our process: We (1) show how the initial story formulated the experience we designed for, an unobtrusive and ensuring way to explore the state of the electric vehicle. The story and derived working principles helped us to maintain this experience throughout all consecutive steps of our process. We (2) provide details on all design steps and representations of the experience including story, storyboard, interface design and prototypes. Moreover we (3) show how we integrated a high-fidelity prototype into the dashboard of a car-mockup considering other devices and safety issues, without violating the requirements derived from the experience story and finally (4) report how lab studies in a driving simulator help to evaluate if the story is communicated and can be reenacted by adapted prototypes in early iterative design stages, before implementing expensive sophisticated prototypes which can later be tested in real driving scenarios. With this we contribute to the field of experience design a new approach to maintain the essence of the experience story despite of several technical constraints emerging during the implementation of interactive prototypes and their integration with other systems.

RELATED WORK

When designing Heartbeat we took three research areas into consideration: (1) electric vehicles and their information systems, (2) eco-feedback and (3) experience design and user experience.

EVs and their Information Systems

To gain an understanding of EV drivers, the UC Davis and BMW conducted a study [35], giving more than 200 electricity-driven MINIs to households in California and New York for one year. As those drivers were new to EVs, they experienced a learning process to understand the behavior of their cars, including the phases "Discovery, Translation and Application" [35]. The MINI E Consumer Study showed that range anxiety, the "continual concern and fear of becoming stranded with a discharged battery in a limited range vehicle" [34], is a concern of inexperienced drivers. If users do not drive an EV over a longer period of time, e.g. when using car-sharing models, it remains a prevalent problem [8]. However, during the learning process they adopt to the capability of the EV by changing their driving behavior or exchanging vehicles with family members when needed [22] [35]. Thus, communicating understandable information about range and energy consumption is one of the most important elements of EVIS [22] [32]. Based on these findings, we designed Heartbeat to help to discover the EV's special characteristics, help drivers to understand the underlying concepts and support in adopting their driving habits to get the best experience out of driving an EV.

Comprehensible in-car feedback systems about the energy state of the EV have a short history and only recently moved into the focus of attention [24]. With EVs lacking audible and haptic feedback of a running car engine, some EVs provide a "Ready" indication [30] by displaying a message or moving the gauge pointer to a specific position.

Strömberg et al. [32] explored two approaches to present EV relevant information integrated into an instrument cluster: (1) transferring combustion specific to EV-specific characteristics, e.g. showing a fuel gauge visualization for the battery state and (2) using horizontal and vertical scales to visualize the battery state in watt. People preferred conventional car visualization to scales, which were perceived as cryptic and confusing because of incomprehensible information. Instead, participants require feedback about battery and motor state, which is easy to understand [32]. We address this issue by providing a metaphor inspired by the human heartbeat, mapping the frequency to the amount of energy currently used and providing additional visual information representing the batteries' state of charge.

Eco-Feedback

As Spagnolli et al. [31] describe in their design principles for eco-feedback, providing real time information about the actual energy consumption is a benefit. Fast eco-feedback can influence the prospective behavior and can therefore for instance help the user to save energy. This approach can be transferred to EVs and influenced our design of Heartbeat in terms of a constant ambient visual feedback and real-time haptic feedback on demand.

Light is a flexible medium providing multiple dimensions for feedback, e.g. color and brightness, making it powerful for complex information transmission about energy, e.g. source and state. The Power-Aware Cord [9] visualizes the actual energy consumption of a product to increase user awareness. Older versions of the Apple MacBook provide feedback about the state of the notebook using a 'breathing' LED [13]. Accordingly, Heartbeat uses color and brightness levels to feedback energy.

Experience Design

Norman formed the concept of Emotional Design [23], stating that the experience that occurs during the interaction with an object highly depends on the emotions aroused in the user. In his model, he describes how products influence the experience by "their attractiveness, their behavior und the image they represent" [23]. Hassenzahl picked up Norman's approach, stressing that designers must consider "experience before design" [10] by formulating an experience story before implementing first prototypes. Based on this principle, Knobel developed an Experience Design process [17], starting out by collecting user stories, extracting story patterns, writing an experience story and implementing mock-ups and prototypes for later evaluations. During the development of Heartbeat, we concentrate on the transition from experience story to a first experience prototype, formulating working principles directly derived from the story and show how we refer to the principles for design decisions throughout the process.

The measurement of a product's user experience remains controversial and is based on several theoretical approaches, but few valid measurement tools. Several studies focus on product attributes by assessing hedonic and usability qualities [14] [19] or aesthetics [20]. Others focus on the experience while interacting with a product. Hassenzahl et al. [11] measured the fulfillment of psychological needs [29], triggering positive affect in reported positively experienced and remembered product interactions. This approach was also successfully applied in the automotive domain in a study about an in-car device to interchange information with other drivers [17].

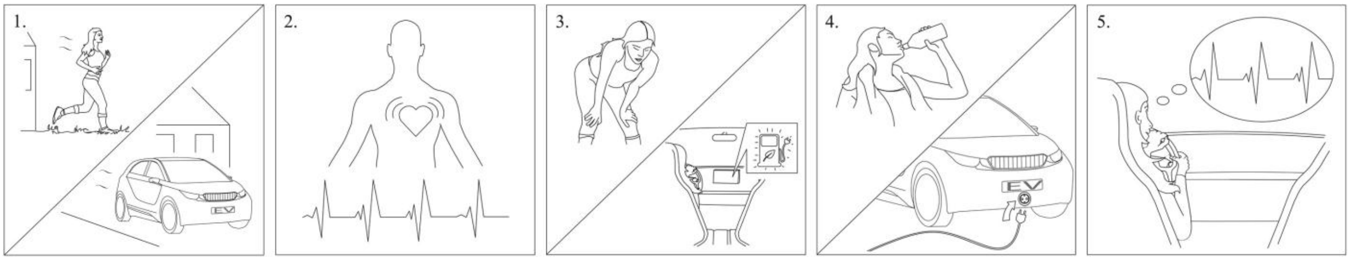

Figure 2. Storyboard illustrating how the heart frequency of a runner can be mapped to the state of the electric drive of an EV

EXPERIENCE STORY & STORYBOARD

The starting point in our design process is the experience story [10] [17]. It formulates the important aspects of the experience we design for without containing details about possible implementations of future prototypes. In order to derive design principles for an interactive system, we strongly suggest to actually provide a written text.

With our goal of communicating the state of the electric drive and the battery to the driver, i.e. showing that the car is 'alive' and ready to go, we drew parallels to the way humans assess their physical state in a similar situation: we put a hand on our chest and literally feel our heart beating. We developed the following experience story, which represents the starting point for the design of the interactive system.

Today, Lisa is going for a run. After taking a little ride out of town, she steps out of her car and increases her awareness of the outside environment. Lisa feels good, kind of active and alive. She slowly starts moving and picks up the pace.

Lisa increases her speed. She feels her heartbeat and how it becomes faster & more intensive. Soon, she finds her perfect pace.

After a while, Lisa is out of breath and starts to slow down. She needs a little break to take a drink and regenerate. Lisa evenly breathes in and out and fills up her body with new energy. She puts her hand on her chest and feels how her heartbeat slows down again. After a couple of moments, she feels ready to start her way back.

Lisa easily makes it back to the car. She gets inside and increases her awareness of the inside. She starts the car and senses its Heartbeat. Everything feels good, kind of alive and active. As Lisa puts her foot on the acceleration pedal, the car starts to move. As it picks up the pace, she can feel how the Heartbeat becomes faster and more intensive.

Half way home, Lisa sees that her car needs a break. She reduces the speed and feels how the Heartbeat slows down. "This way, I will easily make it home." After parking her car in the garage, she connects it to the wall outlet. "Good night" Lisa says, "see you tomorrow!"

An additional storyboard (see Figure 2) helped us to visualize the moments and interactions most important for the actual experience. We used five key frames to illustrate the parallels between a human heartbeat and the energy state of an electric vehicle. Story and storyboard helped us (1) to get a better understanding [5][25] of the metaphor and the mapping to the EV context, (2) to communicate our idea [5][25] to team members in an understandable way and (3) to derive ideas and requirements for a first implementation of a working hardware prototype.

CONCEPT & INTERACTION DESIGN

Before implementing an early prototype, we suggest to derive a list of working principles from the experience story. Each item describes a property that each future iteration of the concept must implement. By following this procedure we ensure a design following the initial experience. Based on the Heartbeat story, we derived the following working principles (P1 - P6), which we will refer to when we describe the prototypes in the following sections.

P1: Heartbeat is activated when the *car's* electric drive is *started*, indicating that it is ready to go (*alive and active*)

P2: *feel* implies a haptic feedback, which is perceivable on demand (*puts her hand on*)

P3: when going faster, the feedback becomes *faster and more intensive*, indicating that more energy is consumed

P4: *see* implies a permanent visual feedback, while *sense* implies an ambient character

P5: Heartbeat shows a low battery charge relative to the current destination (*home*); a recharge (*break*) or a lower energy consumption (*reduce speed*) is needed

P6: when *reducing the speed*, the visual feedback adopts depending on the updated energy consumption

With these principles in mind, we developed first sketches [5] of a potential Heartbeat interface. Figure 3 shows a device placed in the center of the dashboard (P4), similar to the location where the human heartbeat is feelable when touching the chest (P2). Heartbeat emits a visible glow (P4) and can be easily reached by the driver to feel haptic feedback (P2). By collecting feedback within the team and iterating the sketches, we developed a clear picture of a first experience prototype (see Figure 1).

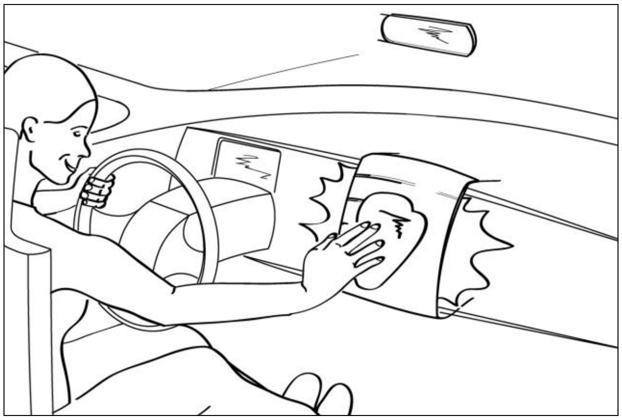

Figure 3. The first scribble of Heartbeat shows an interface in the center of the dashboard, easily reachable for the driver

EXPERIENCE PROTOTYPE

In the next step, we implemented the design concept in the form of an experience prototype (see Figure 4). This first implementation helped us not only to communicate our idea to others, but also to truly try it out and collect detailed feedback on the concept and the experiences during interaction. As a prototyping and testing platform, we used a static car mock-up consisting of both front doors, a windshield, driver and passenger seats, a dashboard and a steering wheel (see Figure 6). The integration into an actual vehicle with all other functions, safety issues and ergonomic principles was not considered at all in this first step to give us the necessary freedom for exploring the concept and building an actual working prototype.

Positioning

We placed Heartbeat into the dashboard's center stack (see Figure 4). This position is easily reachable (P2) for both driver and co-driver, and visible (P4) to all passengers. Furthermore, this position matches the heartbeat metaphor, in which the heart is a central organ of the human body.

Outside Appearance

The prototype has the shape of a hemisphere and sticks out of the dashboard (see Figure 4). We chose a diameter of ten centimeters for providing an anatomical shape to feel the haptic feedback (P2) with both palm and fingers. These parts of the hand are especially sensitive to slight pressure and vibrations [1]. In reference to the story, the combination of shape, size and subtle glowing of Heartbeat provided an affordance, inviting passengers to touch it (P2) and feel the haptic feedback and therefore the state of the EV's electric drive. The lower visual part of Heartbeat is made out of acrylic glass. The surface was carefully sanded, making it semitransparent. Thus, while being in an inactive state, this part would not attract direct attention (P4).

The luminous scale below Heartbeat provides qualitative and relative information about the attainability of today's destinations with the current battery charge and driving behavior (P5 & P6): the narrower the stream of light, the more likely the need for a recharge. We purposely abstained from exact mappings of electric charge to display values, because that would have contradicted the ambient and subtle nature of the display (P4).

Interaction

With an ambient glow of Heartbeat and the scale (see Figure 4), the driver receives a hint that the car is ready to go (P1) and the batteries are sufficiently charged (P5). Since this feedback is perceivable in the visual periphery [38], no attention shift is needed. If the driver is looking for an explicit and more detailed feedback about the energy consumption, she can touch Heartbeat and feel the haptic feedback (P2). Just like the runner touching her chest, this feedback is only provided on demand and will thus not disturb the driver at any other time. With visual and haptic feedback we stimulate more than one sensory modality (P2 & P4), which was found to enable richer experiences [28].

Visual Feedback

The prototype provides visible feedback to all passengers in an ambient way without distracting from the primary task of driving. As soon as the EV is started, Heartbeat awakes according (P1) by a slow increase of the luminance. The prototype glows in a blue color representing power and energy [2], matching the EV context, as well as vitality [2], referring to the heartbeat metaphor.

A strip of eight RGB LEDs provides the visual feedback for Heartbeat, the scale consists of another three strips. The light sources are dimmable, which allowed us to adapt the brightness to the outside lighting conditions and in case of the scale to the current battery charge. This was necessary to find the right balance and offer an ambient source of information without distracting the passengers (P4). The semitransparent acrylic glass diffuses the LED light, making it visible all over the surface.

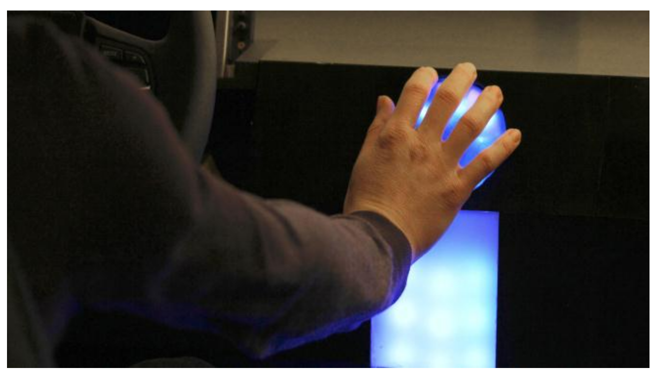

Figure 4. First experience prototype of Heartbeat and the energy scale, placed in the dashboard of a car mock-up

Haptic Feedback

The most characteristic feature of the prototype, symbolizing the car's heart, is the haptic feedback (P2), which is activated as soon as the electric drive is turned on and the car is ready to go (P1). When touching it, the driver can feel vibrations strongly reminiscent of the rhythm of a beating human heart, as described in our experience story. We also chose haptic feedback, because it is only perceivable on demand, i.e., when actively touching the prototype (P2). A visible pulsation of the same speed would distract the driver and become irritating over time. The frequency of the Heartbeat vibrations are directly mapped to the energy consumption of the electric drive, which is besides light, air conditioning or infotainment systems mainly determined by the EV's speed and acceleration. The faster the car is going, the faster is the rhythm of the Heartbeat (P3), indicating high energy consumption.

We implemented the haptic feedback by using an off-the-shelf 10W speaker placed behind the dashboard such that its membrane is barely touching the surface of the plastic sphere. This setup transfers the vibrations of the membrane directly onto the acrylic glass whenever a sound is played via the speaker. To ensure that this haptic feedback is still perceptible when touching the sphere, the prototype was not fixed to any of the solid parts surrounding it, but cushioned to all sides using a soft foam material.

Preliminary Evaluation

The advantage of a first low-fidelity but high-resolution experience prototype [4] in this early stage of the design process is the ability to collect early feedback. During expert interviews and small user studies we investigated whether drivers understood the concept behind Heartbeat and if they were able to re-live elements described in our experience story during the interaction. The experts were seven researchers and professionals in the fields of human-computer interaction, ergonomics, psychology, industrial design and product development. In three user studies, we conducted interviews with 36 participants after interacting with the Heartbeat experience prototype in a car mock up (as described in section 0) without a driving simulation. By analyzing qualitative feedback, we collected evidence indicating whether the working principles (see section 0) have been successfully implemented.

First of all, the Heartbeat metaphor (P1) was recognized in statements such as "it is beating like a heart, so I think the car has enough 'juice'" or "it feels alive, almost organic" or "I feel that my car is fit". The haptic feedback, which is perceivable on demand (P2), was expressed in "I can only feel that if I want to" or "I can also get feedback without looking at the dashboard" or "I can feel how my car feels". Visual feedback (P4) was mentioned in "a short glance was enough to get what's going on". The ambient light was often mentioned in relation to the need for being in control, e.g. "I was able to see that I am doing the right thing" or "nice and aesthetic light let me feel safe". Note that Heartbeat was not used in driving situations in this early stage, so that the feedback did not change due to energy consumption or driving speed (P3, P5 & P6).

We also gathered feedback valuable for the next iteration of Heartbeat. "A vertical energy scale, like a thermometer, would be more understandable" and "I couldn't read any energy related information" and "when I had my hand on the sphere, my arm occluded the scale" led to a new concept for the energy scale with a vertical indicator above Heartbeat. Statements such as "I just always wanted to touch the prototype and was disappointed that I could not do anything with it" and "why is there no interaction possible?" and "there should only be light after I actively started the vehicle" (P1) motivated us to integrate interactivity to the Heartbeat concept, e.g. by integrating the start-stop-functionality of the car. Several participants noted that the haptic feedback was not strong enough, motivating us to try different ways to produce the vibrations.

EVOLUTION AND INTEGRATION

To be able to create a novel electric vehicle information system [24], Heartbeat had to evolve into a more mature prototype. A major challenge was the conceptual integration into an existing dashboard. In cooperation with a major car manufacturer, we were able to create a list of devices and functionalities that have to be considered when changing and integrating an existing interface into a car. This included air condition, infotainment system, airbags and the glove compartment. Emerging constraints included space requirements, ergonomic principles, safety aspects as well as the following further design considerations.

Positioning and Functionality

In contrast to the minor constraints that we took into account for the first experience prototype, Heartbeat now needed to be positioned with respect to other devices and functionalities. Because of the typical position of infotainment systems and air conditioning controls in the center stack, it was not possible to keep a dedicated device in the center of the dashboard.

Instead, we tried to integrate Heartbeat into the steering wheel, due to the easy reachability (P2, see section 0). The fact that the vibrations would be omnipresent when steering violated the on-demand-character of the haptic feedback (P2) as well as safety issues in case of a crash prevented us from realizing this position. Another option was the armrest between the front seats. This position is easily reachable (P2) but is outside of the peripheral vision of the driver and does therefore not meet the requirement of providing visual feedback (P4).

Out of several possible new positions, we finally chose the start-stop-button (see Figure 5). It is easy to reach (P2), integrated haptic feedback will only be feelable on demand (P2) and visual feedback will be perceivable in the periphery (P4). It is an important advantage of the start-stop-button that the driver already has one hand on the interface whenever starting the EV, being able to instantly feel Heartbeat (P1) and check the electric drive's state.

Since the start-stop-button is used to turn the electric drive on and off, it is also predestined to integrate other energy-related functionalities. Hence we added the control for choosing between the driving modes 'Eco-Friendly' and 'Agile'. This additional functionality supports the adoption of the visual feedback of the energy scale (P6): when switching into the Agile mode, the increasing energy consumption might change the ability to reach the destination with the current battery level (P5), and vice versa, which will be indicated by our energy scale (see Figure 5).

Outside Appearance
To provide the affordance for pushing (on/off) and turning (driving mode), the interactive element of the Heartbeat now consists of an aluminum cylinder with a diameter of four centimeters, encircled by an acrylic glass ring. Compared to the first prototype, Heartbeat is now smaller and positioned closer to the driver (P2), still supporting the idea of ambient visual feedback (P4). The energy scale (P5) is now visible above *Heartbeat*, consisting of seven small bars. Next to *Heartbeat*, two labels represent the driving modes 'Eco-Friendly' and 'Agile'.

Figure 5. New Heartbeat prototype integrated into the Dashboard respecting constraints of other devices

Visual Feedback
Visual feedback (P4) is again given by LEDs, now installed behind the acrylic glass ring. The interactive element itself does not provide any visual cues, making the interface less distractive and more ambient (P4). Each bar of the scale can be illuminated, which shows the current charge of the EV in analogy to the familiar visual element of a charge bar (see Figure 5). If the illuminated bars drop below a marked position e.g. when changing the driving mode (P6), a recharge will be needed to reach today's destinations (P5) known from the driver's calendar. The label with the currently active driving mode is illuminated.

Haptic Feedback
The choice of a new interactive element representing the Heartbeat required another way to provide haptic feedback (P2) compared to the first prototype. We integrated a vibro-tactile transducer into the aluminum cylinder. Its vibrations are transfused to the interactive element and can thus be perceived when touched by the driver (P2). The transducer is connected to a computer's soundcard, converting any audio signal into corresponding vibrations, in our case implementing the rhythm of a beating human heart. Depending on the energy consumption, the 'heart frequency' increases (P3), e.g. in the Agile driving mode due to higher speeds, and decreases in the Eco-Friendly mode due to economical driving.

In sum, the evolution turned Heartbeat into an interactive and driver-oriented interface for experiencing and influencing the energy state of the EV. This interface still includes the essential elements of our initial experience story, but now also responds to the technical requirements of the EV, such as the physical and functional constraints in the dashboard, as well as the need to communicate additional functionality, such as the driving mode.

EVALUATION OF HEARTBEAT
By integrating Heartbeat into the dashboard of a car-mockup following constraints such as space requirements, we changed the position and appearance of the prototype and added additional functionality. Although we used the story and the derived working principles (see section 0) as a reference point to ensure a consistent experience, an evaluation is essential to show that the story and the designed experience is still communicated during the interaction with Heartbeat. We follow the approach of Hassenzahl (see section 0) in this study: Heartbeat was designed to create an experience by fulfilling the psychological needs for stimulation and control. We hence used a need questionnaire, the PANAS questionnaire to check for evoked emotions and an interview to see whether the intended needs were fulfilled in the interaction situation and whether the interaction was perceived as a positive experience.

Measures
We measured the fulfillment of the psychological needs for stimulation and control with the UXNQ [16] containing five representing items per need scale. Participants indicate their agreement with a statement on Likert scales from 1 ("strongly disagree") to 5 ("strongly agree"). Example items are "I made a fascinating new experience" for the stimulation scale and "I could successfully master the situation" for the control scale. We considered a need as fulfilled if the mean score was rated higher than the scale mean 3 ("moderate agreement"), because this means rather agreement then disagreement and thus rather fulfillment.

To assess the affect resulting from the product interaction, we used a German translation [18] of the PANAS questionnaire [15]. It consists of a positive affect scale (high energy, pleasurable engagement; PA) and a negative affect scale (distress, unpleasurable engagement; NA) that are seen as independent dimensions of affect. We expected that the novel and interesting form of feedback addresses stimulation and thus leads to a positive experience measured by positive affect. We therefore expect a positive correlation between the stimulation scale and the PA scale. Furthermore, Heartbeat always informs the driver about the vehicle's energy state and therefore should fulfill the need for control. Perceived high control should reduce distress, thus we expect a negative correlation between the control scale and the NA scale.

In addition to the questionnaires, participants gave feedback in an interview about what they liked about the product and what they would improve. Using the laddering method [26], we repeatedly asked the participants why they liked an aspect in order to identify the underlying values and needs.

As a behavioral measurement we told the participants at the end of the experimental session that they have to answer some questionnaires now, but that they were free to continue to interact with the prototype. We considered a voluntary extension of the experimental session as an indicator of intrinsic interest in Heartbeat.

Study setup and procedure

The study took place in a laboratory of a university with a total of 34 participants, 17 (50 %) female. The mean age was $M = 23.9$ ($SD = 4.3$) years, ranging from 20 to 40. All were recruited via a mailing list and received a reward in form of a 10 euro voucher. All participants were fluent in German and experienced drivers. To simulate a driving situation, we used a car mockup and a driving simulator. The simulator software (SILAB 3.0 by WIVW GmbH) was projected on the wall in front of the mockup (distance 2 m). The input device was a Logitech Driving Force GT steering wheel with pedals.

Figure 6. A participant experiencing Heartbeat in a simulator

Several User Experience frameworks [12] [27] stress the importance of the interaction's context, i.e. the environment of the usage situation that is independent from the product itself. Because the context determines the user experience and thus the psychological needs that are fulfilled in an interaction [16], we embedded the interaction with Heartbeat in a context-creating story. We introduced participants to the story with a storyboard and additional verbal explanations and asked them to put themselves in the perspective of the main protagonist.

Imagine you want to drive to the bakery in the morning with your new electric vehicle. After starting the vehicle with the start-stop button, you will be able to feel the state of the electric drive. You can also change the driving mode by turning the start-stop button. With the help of the scale you can find out whether the batteries are sufficiently charged to reach your current destination. When reaching the bakery, please park the car and turn it off.

The experimental procedure was as follows: At the beginning, participants completed a training drive for about five minutes until they felt familiar with the simulator. Next, we presented the story and gave participants time to re-live the scenario presented in the storyboard. They used Heartbeat in the experimental drive that lasted about five minutes. At the end of the experiment, the questionnaires were answered and the interview was conducted.

Results

Table 1 shows the descriptive values for the used questionnaires. In a first run of experimental sessions, only the questionnaire UXNQ was used and therefore ten participants did not answer the PANAS questionnaire. Four items of the control scale (2.35%) have not been answered and have been replaced by the individual mean. As expected, participants agreed that both stimulation ($M = 3.86$, $SD = 0.66$) and control ($M = 3.87$, $SD = 0.72$) have been fulfilled during interaction.

	N	*M*	*SD*	α
Stimulation	34	3.86	0.66	.81
Control	34	3.87	0.72	.79
Positive Affect	24	3.39	0.43	.38
Negative Affect	24	1.49	0.41	.62

Table 1. Descriptive values of the PANAS and need scales

One-sample t-tests revealed that stimulation ($t(33) = 7.68$, $p < .001$) as well as control ($t(33) = 7.01$, $p < .001$) were rated significantly higher than the scale mean of 3, which represents the first answer category that is an agreement with the statement. Thus, scores above this mean represent rather fulfillment than non-fulfillment. The effect sizes of the results, which are independent of sample size, are large with r = .80 for stimulation and r = .77 for control [6].

Both need scales possess good reliability [21], but, although it can be considered a reliable affect measurement that has proven his psychometric quality in numerous empirical studies (e.g. [7] [36]), we obtained low respective acceptable reliability scores for the positive and the negative affect scale of the PANAS (see Table 1). The scale reliability would rise to .50 if the item "alert" would have been deleted. The mean of the positive affect (PA) scale scores slightly above the scale mean ($M = 3.39$, $SD = 0.43$), i.e. participants perceived the interaction moderately euphoric. Negative affect (e.g. distress) was rated low ($M = 1.49$, $SD = 0.41$).

We calculated multiple correlation coefficients (Pearson's r), to analyze the relationship between need fulfillment and affect. First of all, no significant correlation between the two need scales was found, the scales can be therefore seen as independent. As expected, stimulation correlated positively with perceived positive affect. There was no relationship between stimulation and perceived negative affect, as expected. The scale control correlated significantly negatively with the negative affect, but was in no significant relationship with the positive affect.

After the experimental session, we asked participants what they liked about Heartbeat and what they would improve. The following statements have been translated from German by the authors. 16 out of 34 participants (47.1%) were pleased by the ease of use, stating "it's a natural interaction, an intuitive, nice metaphor", "easy to use and not confusing" or "usable without a manual". Also, 19 (55.89%) participants positively mentioned the kind of feedback: "I liked the Heartbeat, it calms me down while driving", "the car was answering me" or "feedback like a heartbeat". The idea of Heartbeat and the metaphor itself were explicitly highlighted by 13 (38.24%) participants. The design quality was positively mentioned by 13 (38.24 %), calling it "of higher value" or "reduced" and mentioned "pleasant lighting".

We used the laddering method [26] to identify the underlying values or needs for the preferences. We identified the need control for 18 (52.94%) participants e.g. when stating "you can clearly see if the engine is running" or "less distraction and therefore more control over the car". For 7 (20.59%) participants, stimulation was the reason for their preferences. Example answers were "novel experience" or "something different and exciting".

Questioned about possible improvements, 18 out of 34 (52.94%) participants suggested that the haptic feedback should be stronger. Also, 4 (11.76%) suggested an initial strong vibration when the electric drive starts and that the haptic feedback should differ strongly between the two driving modes (6; 17.65%).

We observed participants voluntarily extending the experimental session, being a behavioral indicator of intrinsic interest in Heartbeat. More than half of the participants (18 of 32 valid cases; 56.25%) tried its functionality and played with it even after the experimenter told them that the experimental sessions is over.

Discussion

The evaluation of the prototype revealed that both psychological needs, stimulation and control, were addressed when interacting with Heartbeat, which is supported by qualitative feedback and the fact that the majority voluntarily experimented with Heartbeat after the study. Concerning positive affect, participants perceived the interaction as only moderately stimulating. However, this is in line with the design of Heartbeat to be a reassuring, enjoyable interface not intended to evoke intense fun or euphoria. The interaction was also perceived as not distressing, supported by statements about the calming feedback indicating that everything is okay. The need for control was in a negative relationship with the negative affect (e.g. distress), saying that the communication of the car's status reduced stress and lead to a relaxing and pleasurable situation. Comments also indicate this relationship and highlighted the ease of use and reduced design in line with the perceived control of the situation.

We conclude that we have successfully integrated the prototype into the dashboard without influencing the designed experience in a negative way. By formulating and strictly following the working principles derived from the experience story, we changed the design (e.g., shape and size) as well as the functionality (e.g., adding input elements) of the experience prototype without violating the essential story elements, ensuring a consistent experience.

CONCLUSION AND FUTURE WORK

Heartbeat is a new kind of interface for electric vehicles, informing the driver about the state of the electric drive as well as the charge of the batteries relative to the current destination. Heartbeat communicates the State of Charge in a non-disturbing, ambient visual way and the current energy consumption providing haptic feedback on demand. Following the metaphor of a human heartbeat and letting the driver explore the energy flow of his EV, we address the psychological need for stimulation. By providing subtle information about the state of the EV, we assure the driver and help to gain control of current and upcoming situations.

Considering our experience design process, we stressed the importance of a written story, which helps to explore, communicate, evaluate and implement a potential experience. From the story we directly derive working principles forming reference points for all design decisions throughout the following phases. We showed how every detail of the user interface design must be motivated by the working principles to ensure a consistent experience design. An early experience prototype helps to directly translate the interface design into an interactive system in order to gain fast feedback showing that the designed experience can potentially by relived by using the prototype. When being forced to respect several constraints while integrating a prototype into a broader context, i.e. the dashboard of a car, we showed how we chose from several design alternatives with the help of the working principles, again ensuring the perpetuation of the designed experience. We provide a qualitative and quantitative evaluation methodology concentrating on the fulfillment of psychological needs and triggered emotions during the interaction with our prototype. Results show that participants reenacted the experience we designed for despite of a number of changes of the prototype in terms of design and functionality, always respecting the experience story and the derived working principles.

However, our evaluation methodology comes with limitations. (1) There is still not a widely accepted method to measure if the design of an experience was successful. We combine quantitative and qualitative feedback assuming that we address certain psychological needs such as stimulation or control, triggering positive emotions. The positive affect scale of PANAS scored with low reliability, which can be increased my removing certain items, in our case “alert”, indicating that the items have to be adapted according to context and situation. Further research is needed to obtain reliable ways to evaluate experiences. (2) Please note that our prototypes and evaluations implemented early stages in the Experience Design process. They are intermediate steps and concentrate on a *conceptual* integration into a broader context to verify whether the designed experience can be reenacted, before spending high effort on the implementation and in-situ evaluation of mature high-fidelity prototypes.

Concerning Heartbeat itself, the study revealed several aspects worth considering when implementing a sophisticated version in a later design phase. Despite being pleased about the subtle nature of the feedback, participants asked for optional detailed information on the state of charge, distance to empty and energy consumption of single devices in the car. This can be solved by displaying contents on the central display when the driver reaches for Heartbeat, which can then be retrieved on demand. Furthermore, participants asked for a stronger haptic feedback, especially when thinking about using the system in actual driving conditions. Specially designed actuators should address this issue.

With this work we enhance the Experience Design process by using working principles that we directly derived from the experience story. This tool supports designers to ensure a consistent experience despite of implementation constraints that might otherwise conflict the essential party of the story.

We hope for further case studies collecting detailed insights into the design, implementation and evaluations of experiences in the car.

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