Energy Flow: A Multimodal ‘Ready’ Indication For Electric Vehicles

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Figure 1.The Energy Flow Prototype.

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Abstract
The lack of sound and vibration while starting the drive system of an electric vehicle (EV) is one of the major differences compared to a conventional car with a combustion engine. Most EVs provide a visual feedback about the energy level to the driver. With *Energy Flow* (see Figure 1), we test if there will be a benefit in terms of attractiveness through adding audible or haptic feedback. First results show a positive effect by addressing several senses – but disprove the hypothesis “the more the merrier”.

Author Keywords
Multimodal Interface; Electric Vehicle; User Experience

Introduction
The slow but consistently increasing distribution of electric vehicles does not only change the way how we refuel (or better: recharge) our cars, it also requires a fundamental reorientation of Human-Machine Interaction (HMI) inside such vehicles [5]. The limited range of EVs implicates a new importance of information about stored energy, estimated range and current energy consumption [18]. Furthermore, factors such as regenerative braking and low noise driving are unfamiliar to former combustion engine drivers [3] [17]. Especially the lack of sound and vibration when the vehicle is started represents a new situation, which leads to a misunderstanding of the vehicle status [4]

[8]. Merely providing a visual feedback in terms of a "Ready" symbol is an insufficient solution [19].

To ensure an understandable and positive communication of this new information, the current design of the HMI needs to be improved [10] [17]. One promising chance to design a more comprehensible but also attractive interface leads through a multimodal approach [12] [13] [15].

With *Energy Flow* (see Figure 1), we aimed at materializing the element of Energy, making it tangible and thus understandable for EV drivers. The multimodal feedback, perceivable through different senses, communicates whether the vehicle is ready to drive or not. In a user study, we concentrated on the attractiveness and natural understanding of the interface communicating the state of the electric drive by sensing the flowing energy in terms of visual, haptic and auditory feedback. Comparing all seven possible feedback combinations, we investigated the following hypothesis:

H1: With more than one addressed sense, the feedback gets more attractive

H2: The greater the number of the addressed senses, the more humanly the feedback

H3: The greater the number of the addressed senses, the more positive is the subjective rating

Results show that the combination of haptic and visual feedback was preferred.

Related Work

The changed technical circumstances in EVs, e.g. considering the driving experience and the sound level, contrast with combustion engine vehicles and thus lead to a rethinking of HMI design [17]. The creation of Electric Vehicle Information Systems (EVIS) [10] offers the opportunity to translate specific characteristics of EVs to the driver in a comprehensible way. We argue that a multimodal user interface is a potential benefit.

The potential of addressing several human senses with a product or interface was demonstrated by Schifferstein and Spence [14]. They assume with reference to several studies (e.g. [2] [16]) that multimodal feedback creates richer experiences. In addition, a potential benefit of multimodal feedback is the flexibility of providing redundant information: If one input channel is busy, we can still perceive the information via another [16]. Particularly in perceptually demanding situations such as driving a car, providing a multimodal feedback could lead to a positive effect [9]. Siewiorek et al. [15] demonstrated the benefits of a multimodal interface for drivers such as increased comfort and efficiency while driving.

In the context of energy perception Backlund et al. [1] underline the relevance of design to "materialize" energy in terms of desirable and attractive products to support the understanding of energy in a natural and human way. Jacucci et al. [7] point out the importance of an aesthetically attractive feedback in terms of effectiveness.

Prototype

To conduct a study concerning multimodal feedback in electric vehicles, we built a custom-made hardware prototype (see Figure 1). In order to realize the integration of the prototype into our car mock-up, it had to be robust, small and easy to grasp.

Figure 2. Setup of the simulator study.

To provide multimodal feedback in terms of sound, vibrations and light, we integrated three different actuators into the prototype. The ambient light (see Figure 1) is emitted by a blue LED. Audio feedback is created by a small speaker. Haptic feedback is produced by a small vibration motor. The vibrations are transmitted to the acrylic glass and are thus perceivable when the prototype is touched.

All feedback variants consisted of the same sinusoidal sequence, which symbolized the flowing energy – respectively the ready-indication of the drive. The sequence was iterated three times in loop, which was a total time of 3 seconds per feedback. That means that the visual signal flashed up three times, as well as the audio signal ringed out three times and the haptic signal vibrated three times – all in the same sinusoidal sequence and with identical length.

All actuators are controlled by an Arduino UNO, which is connected to a laptop via USB. Using a simple interface, all seven possible combinations of feedback types can be activated separately, including each single type, any combination of two and all three at once.

To provide a neutral visual nature, we included all electronic parts in a small chassis. We chose a sphere made out of acrylic glass (see Figure 1) with a diameter of 4 centimeters, which can be grasped by a hand in a comfortable way. We polished the sphere with sandpaper, making it opaque for views from the outside but at the same time diffusing the light emitted by the LED on the inside.

User Study

In the conducted study we provided participants with both, unimodal as well as multimodal feedback-combinations representing the state of the electric drive of the EV. We collected quantitative and qualitative feedback to find evidence for the preferred type of feedback.

The sample of this study consisted of 21 participants, ten female, with a mean age of M = 25.1 (SD = 3.6). After the study, each participant received a 10 Euro gift card. For a more realistic setting, we performed the study in a car mockup equipped with a driving simulator (see Figure 2). The used driving simulator software was SILAB 3.0 (by WIVW GmbH).

At the beginning of the study we presented the following scenario: *You finally got your new electric vehicle and charged it for the first time. Now you want to go for a joy ride in the surrounding area. After entering the car, you are unsure about the state of the electric drive.*

We asked participants to feel, see or hear if the electric drive of the vehicle is energized and the car is ready to make the trip. To test all variations of feedback, the situation was repeated seven times. Using the Wizard of Oz method, the experimenter ("Wizard") used a laptop next to the car mock-up to trigger the feedback randomized using a Latin square.

After each type of feedback, we requested participants to provide a subjective rating on a clipboard placed directly on the dashboard next to the interface (see Figure 2). To avoid driver distraction, they operated the interface only in a non-driving condition. We measured the attractiveness of the prototypes by two items of the respective scale taken from the short version of the AttrakDiff questionnaire [6]. The AttrakDiff is an instrument to evaluate interactive products. Each of the chosen items is a semantic differential, ranging from bad to good and from ugly to attractive. Additionally, we used the item technical–human (humaneness) from the pragmatic quality scale to find out more about the perceived character of the feedback.

At the end of each experimental session we conducted a semi-structured interview to collect qualitative feedback and let participants pick their favorite type of feedback and the feedback that they considered as most easy to use.

Results

Figures 3 (attractiveness) and 4 (humaneness) show the mean ratings. We conducted a one way ANOVA to find whether the feedback variants differed significantly. This was not true for attractiveness ($F(6,140) = 1.74$, $p = .117$) but for humaneness ($F(6,140) = 9.452$, $p < .001$). Post-Hoc tests revealed that visual only feedback is seen significantly less human than the other variants. Also, the auditory version was seen significantly more human than any variant providing visual feedback.

Participants' choices for their favorite and for the most usable variant are listed in Table 1. In 66.6% of the cases, the favorite variant was also seen as the most usable. This relationship was significant ($\chi2(36) = 67.43$, $p = .001$).

Conclusion and Future Work

In this paper we introduced *Energy Flow*, a multimodal interface for EV drivers to provide feedback about the work on multisensory experiences, one could expect results in favor of the combination providing all three modalities at once.

However, participants voted haptic feedback (23.8%) as their favorite variant and visual feedback (23.8%) as the most simple one. This disproves hypothesis H3, that the subjective rating would be more positive, the greater the number of addressed senses. In terms of attractiveness, the combination of both, i.e. visual (most simple) and haptic feedback (favorite), was rated best, even though this result was not significant.

	Favorite Variant		Most simple Variant	
Feedback	**#**	**%**	**#**	**%**
visual	2	9,5	5	23,8
haptic	5	23,8	3	14,3
auditive	3	14,3	2	9,5
visual/haptic	4	19,0	3	14,3
visual/auditive	3	14,3	2	9,5
haptic/auditive	1	4,8	3	14,3
visual/haptic/ auditive	3	14,3	3	14,3

Table 1. Choices (number # and percentage %) for participants' favorite and most simple feedback combination.

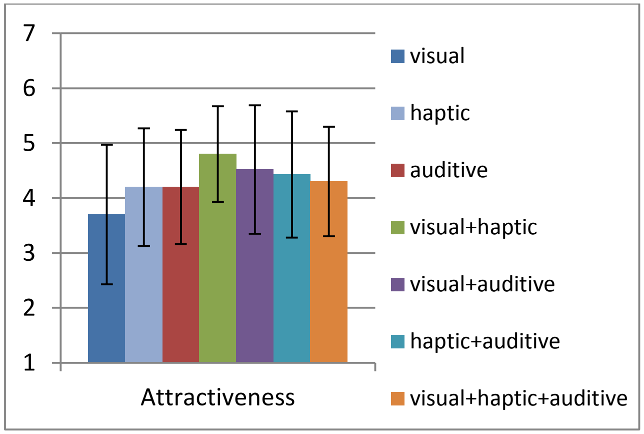

Figure 3. Means of the attractiveness scale.

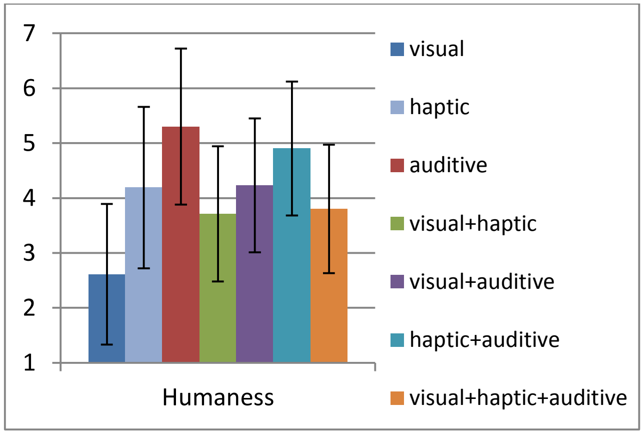

Figure 4. Means of the technical-human item.

Consequently, hypothesis H1 can be partly confirmed. Indeed bimodal and multimodal variants received a higher rating of attractiveness compared to single modalities, but this means not automatically that the most attractive version is addressing all three senses. Auditory feedback and all combinations containing audio cues are rather average rated. A possible reason gathered from qualitative statements is that auditory signals could be predominated by other noise in the vehicle interior (e.g. music and driving noise). The variant with the highest rating of humanness was the unimodal auditive version, which disproves H2. Considering qualitative feedback, the item technical–human was rated ambiguously. Participants considered the provided rhythm of the feedback to be similar to a human heartbeat. Some were positively impressed, others were rather disaffected.

Bringing the results from the attractiveness scale (visual+haptic), the favorite variant (haptic) and the most simple variant (visual) together, a combination of visual and haptic feedback is a good approach to continue work on *Energy Flow* - nevertheless the narrow majority should be kept in mind.

Regarding future work, participants recommended an elaboration of *Energy Flow* concerning a more obvious mapping and a combination with a more detailed scale of the energy level. Another interesting question is what happens if *Energy Flow* turns from a pure output device to an interactive interface were drivers do not only feel the energy but can also control all energy relevant features of the EV (e.g. changing the driving mode from 'Eco' to 'Sports').

This study was just the first step in our design process conducted with a rapid prototype to collect early feedback. We are confident that multimodal feedback is a convenient and attractive way to inform the driver whether there is sufficient energy available.

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References

[1] Backlund, S., Gyllenswärd, M., Gustafsson, A., Ilstedt Hjelm, S., Mazé, R., and Redström, J. STATIC! The Aesthetics of Energy in Everyday Things. In *Proc. of Design Research Society Wonderground International Conference*, Lisbon, Portugal, 2006.

[2] Bahrick, L.E., Lickliter, R. Intersensory Redundancy Guides Attentional Selectivity and Perceptual Learning in Infancy. *Developmental Psychology*, 36(2), 190-201, 2000.

[3] Bühler, F., Neumann, I., Cocron, P., Franke, T. and Krems, J.F. Usage Patterns of electric vehicles: A reliable indicator of acceptance? Findings from a German field study. In Proc. Of the 90th

[4] Cocron, P., Buhler, F., Neumann, I., Franke, T., Krems, J.F., Schwalm, M. and Keinath, A. Methods of evaluating electric vehicles from a user's perspective - The MINI E field trial in Berlin. *Intelligent Transport Systems, IET*, Vol.5 (2). (2011), 127-133.

[5] Gkikas, N. Automotive Ergonomics: Driver-Vehicle Interaction. CRC Press/Taylor & Francis Group, Boca Rotan, 2013.

[6] Hassenzahl, M., Burmester, M., & Koller, F. AttrakDiff: Ein Fragebogen zur Messung wahrgenommener hedonischer und pragmatischer Qualität. [AttrakDiff: A questionnaire to measure perceived hedonic and pragmatic quality.] In J. Ziegler & G. Szwillus (Eds.), *Mensch & Computer 2003*. Interaktion in Bewegung, 187–196. Teubner, Stuttgart/Leipzig, 2003.

[7] Jacucci, G., Spagnolli, A., Gamberini, L., Chalambalakis, A., Björksog, C., Bertonici, M., Torstensson, C., Monti, P. Designing effective Feedback of Electricity Consumption for Mobile User Interfaces. *PsychNology Journal*, 7(3), 265-289, 2009.

[8] Kurani, K.S., Axsen, J., Caperello, N., Davies, J. and Stillwater, T. Learning from Consumers: Plug-In Hybrid Electric Vehicle (PHEV) Demonstration and Consumer Education, Outreach, and Market Research Program. Institute of Transportation Studies, University of California, Davis, 2009.

[9] Lee, J.-H. Spence, C. Assessing the benefits of multimodal feedback on dual-task performance under demanding conditions. In *Proc. BCS-HCI '08,* British Computer Society (2008), 185-192.

[10] Loehmann, S., Osswald, S., Gleyzes, D., Bengler, K., Tscheligi, M., and Butz, A. EVIS 2013 - 2nd Workshop on Electric Vehicle Information Systems In *Adj. Proc. AutomotiveUI 2013*, ACM Press (2013), 7-9.

[11] Oviatt, S. Multimodal Interfaces. In Jacko, J. A. (ed.) *The human-computer interaction handbook fundamentals, evolving technologies, and emerging applications.* 405-430. CRC Press, Boca Raton, 2012.

[12] Pfleging, B., Schneegass, S. and Schmidt, A. Multimodal interaction in the car: Combining speech and gestures on the steering wheel. In *Proc. AutomotiveUI, 2012,* ACM Press, 155-162, 2012.

[13] Politis, I., Brewster, S., Pollick, F. Evaluating multimodal driver displays of varying urgency. In *Proc. AutomotiveUI, 2013,* ACM Press, 92-99, 2013.

[14] Schifferstein, H.N.J., Spence, C. Multisensory product experience. In Schifferstein, H.N.J. & Hekkert, P. (Eds.) *Product Experience*, 133-161. Elsevier, Amsterdam, 2008.

[15] Siewiorek, D., Smailagic, A., and Hornyak, M. Multimodal Contextual Car-Driver Interface. In *Proc. ICMI'02*, IEEE Computer Society (2002), 367-373.

[16] Spence, C. *The ICI report on the secrets of the senses.* Report. The Communication Group, London, 2002.

[17] Strömberg, H., Andersson, P., Almgreen, S., Ericsson, J., Karlsson, M., and Nabo, A. Driver interfaces for electric vehicles. In *Proc. AutomotiveUI 2011*, ACM Press (2011), 177-184.

[18] Turrentine, T., Garas, D., Lentz, A. and Woodjack, J. *The UC Davis MINI E Consumer Study*. Technical Report. Institute of Transportation Studies, University of California, Davis, 2011.

[19] Wellings, T., Binnersley, J., Robertson, D. and Khan, T. *Human Machine Interfaces in Low Carbon Vehicles – Market Trends and User Issues*. Technical Report, 2011.