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AN INVESTIGATION OF VEHICLE INTERFACE OPERATION COMFORT

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ABSTRACT
Comfort of operation is essential for product success. In particular, the evaluation of comfort can be difficult because variations exist in product interface operations. In this paper, we investigated the elements of comfort by capturing comfort during-the-operation as subjects operated a vehicle device interface. We focused on Skin Conductance Response as an indicator of human comfort. We conducted an experiment to investigate the operation of three types of devices contained in two different vehicles. We analyzed a set of quantitative parameters of Skin Conductance and compared them to conventional evaluations of comfort of devices that were collected using a questionnaire. With respect to the operation of these three types of devices, the results revealed a common tendency between these parameters and subjects' evaluations. Investigation of comfort based on Skin Conductance Response can assist in the comparison of the comfort of different devices operations. We also outline suggestions for future research related to evaluation of comfort during vehicle interface operations.

Keywords: user centred design, experience design, comfort of interface operation, vehicle device interface

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1 INTRODUCTION

During product design, designers must consider that users' experiences include a variety of utilities and emotions. Overall, users desire comfort when they operate products. In addition, products must function in ways that are congruent with users' feelings. Users' feelings of comfort (i.e., comfortability) when they operate product interfaces are critical components that determine the success or failure of designed products. Arguably, comfort is an essential part of total human sensitivity towards products. Previous studies have approached comfort from a number of different viewpoints, including physical and operational ergonomics (Kolich, 2008) or cognitive comfort (Walker et al., 2001). However, aspects of comfort can be difficult to capture. Frequently, products designed to satisfy requirements suggested by these viewpoints, do not allow desired comfort during real world operations of product interfaces.

To address these issues, we want to grasp a quantitative evaluation of comfort during-the-operation. For this purpose, we rely on Skin Conductance as an indicator of comfort of operation. On the basis of an experiment in which data were collected during operation of devices in vehicles, we analyze a set of quantitative parameters of Skin Conductance and compare them to conventional evaluations of comfort of devices that were collected through a questionnaire.

1.1 Definition and framework

In this paper, we define the term, *comfort*, to mean pleasurable feelings of ease and freedom from stress that occur during users' operations of product interfaces. The term reflects the degree to which the operation matches inner human sensitivity.

This effort to capture comfort, which is the opposite of discomfort, was performed based on a framework we developed to capture total human sensitivity during product interface operations (see Figure 1). Recently, different techniques have been developed to capture all aspects of deep impressions humans perceive during interaction with product. These include techniques that employ virtual impression networks (Taura et al., 2011) or virtual concept generation (Taura et al., 2012). We believe comfort is perceived by humans in an internal manner. Therefore, comfort is related to human inner sense (Taura and Nagai, 2012). As a result, researchers may struggle to capture and express human perception of comfort. In this study, we attempted to capture comfort that occurs independently from human perception of comfort.

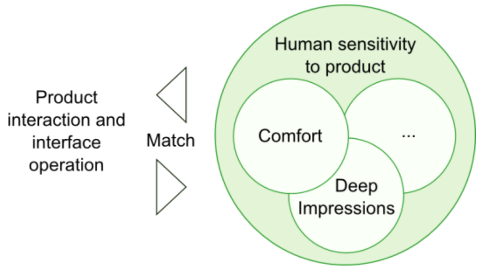

Figure 1. Framework to capture total human sensitivity to products.

1.2 Difficulties capturing comfort

The capture of comfort is difficult to achieve during-the-operation of the product interface. The most common method of capture, which is performed after completion of the operation, is achieved when humans provide descriptions of comfort that contain explicit evaluations (e.g., evaluations collected by the Semantic Differential (SD) method). However, the following issues arise with respect to the capture of comfort following completion of the operation:

- Capture following completion can alter users' indications of the actual state of comfort because of differences in result of comparative evaluations or because of omission of information.
- Users may forget the actual state of comfort.

When we consider during-the-operation evaluations of comfort, a number of different approaches can be applied to these difficulties. However, an approach that relies on explicit self-evaluation of the subject may also alter the actual state of comfort.

Thus, we first focused on methods to capture comfort during-the-operation.

2 AIM AND BASES OF THE RESEARCH APPROACH

The aim of the study was to investigate a quantitative evaluation of comfort and to capture users' comfort during-the-operation of an interface.

We relied on an approach that allows data capture during-the-operation. In a previous study, we devised a method that allowed investigation of human sensitivity based on in-depth analysis of free verbalized impressions (Georgiev et al., 2012a). In the current study, to achieve during-the-operation capture of human comfort simultaneously with free verbalized impressions, we examined a product where the comfort of operation is essential: a vehicle. The comfort of device operations conducted in vehicles is not easy to capture. In addition, many devices installed in vehicles have increased the complexities inherent in this issue.

To achieve our goal, we investigated three devices installed in two vehicles (passenger cars). We observed the air conditioners, audio systems, and navigation systems installed in two different vehicles. These devices could be controlled by knobs, buttons, display (touch panel) in Vehicle 1 and remote controller in Vehicle 2 (see schemas in Figure 2).

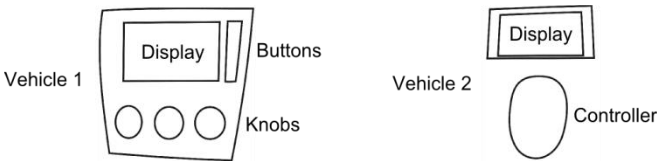

Figure 2. Devices controlled by knobs, buttons, display and controller in Vehicles 1 and 2.

2.1 Psycho-physiological approaches

Different approaches to the capture of human states by the use of physiological and psycho-physiological approaches have been developed (Healey and Picard, 2005). However, a common difficulty among these approaches lies in the complexity of capture and analysis (Christoforidou and Motte, 2009).

Thus, we focused on a simple approach. In particular, we focused our attention on quantitative evaluation of comfort during the operation of devices installed in the test vehicles. We relied on Skin Conductance biosignal as an indicator. Skin Conductance refers to changes in the electric conductance of the human skin due to changes of perspiration (psycho-physiological indicator).

As a future goal, we will include feedback collected from this indicator of comfort during our holistic investigation of human sensitivity to device operations.

2.2 Theoretical bases

Skin Conductance (SC), or, in more general terms, Galvanic Skin Response (GSR), includes a slowly-changing tonic component that usually indicates the Skin Conductance Level (SCL), and a rapidly-changing phasic component that usually indicates the Skin Conductance Response (SCR) (see Figure 3). In other words, the tonic level of SC is the absolute level of conductance in the absence of measurable phasic response (Dawson et al., 2007). Phasic increases of conductance (SCR) are superimposed on the tonic level. Partially-overlapping phasic responses (SCR) are superimposed on a slowly changing level of SCL (Benedek and Kaernbach, 2010).

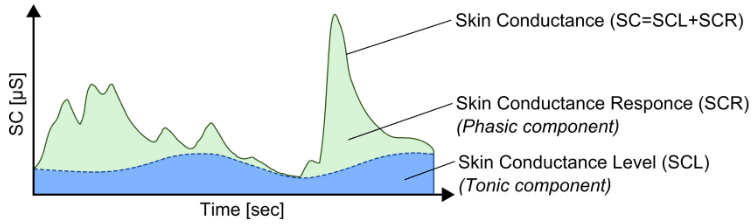

Figure 3. SCL and SCR components of Skin Conductance (SC).

The SCR component of SC increases on arousal. SCR amplitudes provide information about the intensity of the state (Dawson et al., 2007). Furthermore, SC has been used as an indicator of emotional states that occur during high arousal or under stress (Boucsein, 2011, p. 31). SC increases during tasks or along with increases in the cognitive load (Shi et al., 2007).

SC, simultaneously captured with other psychophysiolgoical measures, has been used to assess arousal level and for affect sensing in the field of Human-Computer Interaction (Hudlicka, 2003). Furthermore, SC has been used for detection of software-induced frustration, for detection of affective reactions such as amusement, or for evaluating usability (Ward and Marsden, 2004). These studies focus on the states in which stimuli induce high arousal. However, in this study we focus on the SC when user operates the product and the arousal is low, i.e. SC as indicator of comfort.

2.3 Skin Conductance parameters as indicators of comfort

According to the above-mentioned theoretical bases, higher SC parameters indicate increased arousal, increases in stress, and possible increases in cognitive load. Thus, higher SC parameters indicate a lack of comfort or an increase in discomfort. Alternatively, lower SC parameters indicate a lack of arousal, a decrease in stress, and a possible decrease in cognitive load. These factors can be interpreted to mean that the subjects experienced a more comfortable situation. Thus, we can hypothesize that SC parameters can be used to predict explicit evaluations of comfort.

2.4 Issues related to Skin Conductance

Despite a long history of scientists' use of Skin Conductance as an indicator of emotional arousal, cognitive load, and comfort, SC measurement is rarely used by design researchers (Kim et al., 2010), even in the design area related to emotions and experiences, where this type of measurement is expected. Related studies have rarely expanded upon the simple experimental stimulus-response framework. In that framework, arousal, cognitive load, and/or comfort are judged on the basis of the quantitative characteristics of responses (i.e., SCR) including onset, amplitude, half-recovery time, and so on. However, during actual interface operation, it can be difficult to divide or extract particular stimuli from the whole operation. Moreover, the exact stimulus (i.e., cause) may not be easily identifiable by the subject. Finally, the interface operation creates an overall feeling of comfort that exceeds the amount of comfort provided by individual elements of the interface.

Furthermore, when SC is captured during real use or continuous operation, it is difficult to be analyzed in a systematic or rigorous manner. Thus, in this study we investigated SC as an indicator of comfort during free and unrestricted operations that imitated, as closely as possible, the actual interface operation. We performed our analysis in a systematical and rigorous manner. We examined SC data for relation to the expressed evaluations based on a Semantic Differential Uncomfortable – Comfortable scale by the use of a questionnaire that we administered to users immediately following their completion of the experiment.

Based on the considerations about SC as indicator of comfortability discussed in sections 2.2 and 2.3 and the fact that conventional evaluations of comfort of devices use the SD method, we decided to elaborate on them in order to capture comfort during-the-operation. Although the SD method is not without limitations, we used it to test the SC as indicator of comfort. Furthermore, we think that using an SC biosignal will be a better approach to evaluate comfortability owing to the considerations discussed in sections 2.2 and 2.3 and the fact that SC is not affected by the limitations of the SD method as discussed in section 1.2.

3 METHOD

3.1 Steps

In our study, we employed the following methods: an experiment that attempted to acquire SC data during device operation, the solicitation of explicit SD evaluations of comfort immediately following users' completion of the experiment, an analysis of acquired SC data, and a correlation analysis that compared calculated SC parameters with explicit SD evaluations.

The particular steps involved are listed below:

- Experiment: Users unrestrictedly operated each of the devices. During device operation, SC data was captured continuously.
- SD evaluations: Following completion of the experiment, a written questionnaire was administered to collect users' responses.
- Analysis of acquired SC data: The data was analyzed systematically by calculating SC parameters.
- Correlation analysis.

3.2 Calculated SC parameters

In analysis of SC data, logarithmic transformations (log transformations) are often employed to minimize skew and achieve homogeneity of variance across different groups (Dawson et al., 2007). Computation of the SC log can significantly reduce the skew and kurtosis of the data. Therefore, that procedure is recommended (Dawson et al., 2007, based on previous works). We did not consider temporal characteristics of SC in this research because the data was not based on the moment of presentation of stimulus in a stimulus-response framework. In this study, to formulate parameters calculated with logarithmic transformations, we applied the following formulas to calculate the raw values of SC: $LogSC = \log(SC+1)$; and the raw values of the amplitudes of SCR: $LogSCR = \log(SCR+1)$, where the SC and SCR are the values obtained in μS (micro Siemens), the logarithmically transformed parameters are measured in log μS.

Parameters prior to the analysis of discrete Skin Conductance Responses (SCR) (see Figure 4):

– Mean (arithmetic) of logarithmic transformation of SC ($\bar{x}_{LogSC}$) [log μS].

Parameters calculated from the results of the detection of discrete SCR (a low threshold of 0.01μS is selected):

– Mean (arithmetic) of logarithmic transformation of amplitudes of SCR ($\bar{x}_{LogSCR}$) [log μS].
– Sum of logarithmic transformation of amplitudes of SCR (Σ_{LogSCR}) [log μS].
– Frequency of the detected SCR (number of detected Skin Conductance Responses per observation period) (ω_{SCR}) [Hz].

All of these parameters quantify the amplitude, magnitude, and frequency of the SCR. Thus, the higher the parameter, the stronger the response is.

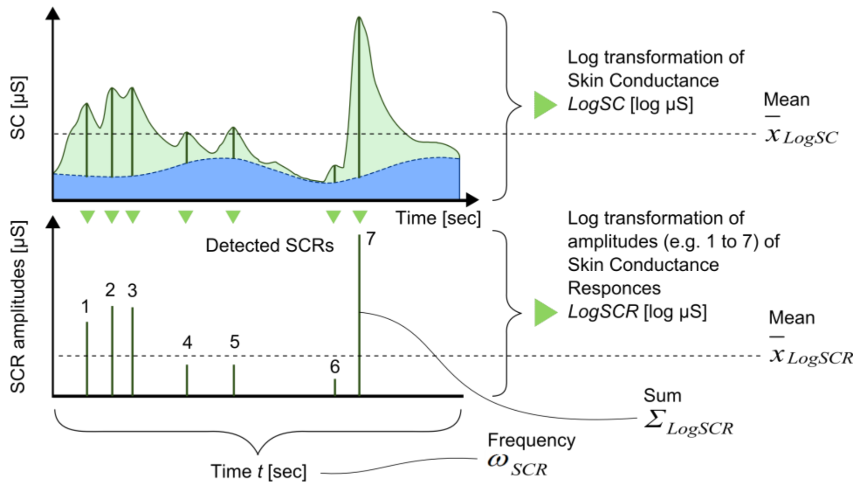

Figure 4. SC and SCR parameters.

4 STUDY

4.1 Setting of the experiment and related procedures

Six subjects (three males and three females) participated in the experiment. One subject was aged between 21 and 25 years, three were aged between 26 and 30 years, one was aged between 36 and 40 years, and one was aged between 41 and 50 years. They operated three devices installed in two vehicles (passenger cars). Subjects operated devices and vehicles in random order. The experiment involving the second vehicle was conducted on a different day. To capture device operation so that it remained as close as possible to real-world operation, we stationary-mounted both vehicles in a designated experimental space to avoid distracting the subjects with other operations. During the experiment, both vehicles' engines were allowed to run. The subjects unrestrictedly operated each of the devices for approximately five minutes during the experiment (average: 325 seconds; standard deviation: 24 seconds). All users performed device operations with their left hands in right-side driver vehicles located in Japan. We requested that subjects verbalize their free impressions of device operations. These verbalizations were unrestricted.

After all subjects completed operations of all three devices operation, we administered a written questionnaire. We asked subjects to provide explicit evaluations on an ordinal SD scale of Uncomfortable – Comfortable (between 1 and 7) for each device.

During the analysis, the three devices that operated the functions of the air conditioner, audio system, and navigation system were considered separately. Thus, with respect to the subjects, vehicles, and devices, we analyzed a total of 36 cases.

4.2 Measurements

To minimize possible disturbing effects from the SC (GSR) sensor, we used a Bluetooth wireless sensor. We placed the sensor on the subjects' right not-operating-at-the-moment hands (Shimmer Wireless GSR Sensor, 2012/01.08.2012). The sensor was placed on subjects' index and middle fingers (the volar surfaces of the distal phalanges). Data from the sensor was wirelessly streamed and saved to a notebook computer. The analysis of the captured SC data was performed following completion of the experiment.

5 ANALYSIS AND RESULTS

The classic approaches used to detect SCR have demonstrated some difficulties including inaccuracies in result of trough-to-peak detection, failure to discriminate SCR located close to one another, and general underestimation of SCR amplitudes. These approaches were inappropriate for our purposes, thus, we focused on systematic and up-to-date approaches to analyze SC data and SCR detection.

Continuous Decomposition Analysis (CDA) is an approach that allows detection of SCR responses collected from SC data (Benedek and Kaernbach, 2010). The actual detection of Skin Conductance Responses based on CDA is performed by the use of Ledalab software (Ledalab V3.4.3, 2012/08.06.2012) in Matlab. An example of continuously-obtained SC data is shown in Figure 5.

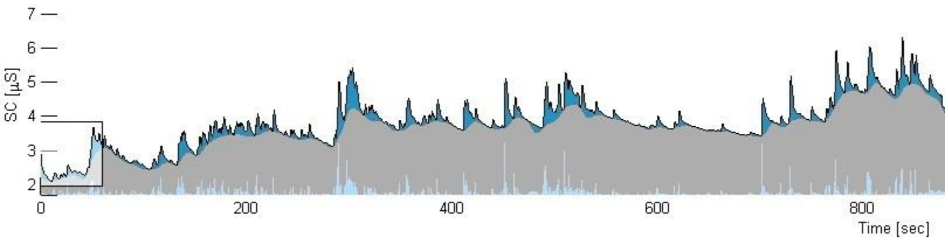

Figure 5. Example of SC data.

To calculate SCR in this study, we devised a procedure that involved the input of raw data collected by the sensor in micro Siemens (µS). The output of the calculation procedure resulted in the calculated parameters of SC and SCR per subject, vehicle, and device. For example, parameters were calculated for subject 1, vehicle 1, and its audio system. They were then calculated for subject 1, vehicle 1, and its device air conditioner, and so on. Based on this procedure, our calculations for six subjects, two vehicles, and three devices resulted in 36 cases of calculated parameters. The calculated parameters were based on previous research conducted in this area (Benedek and Kaernbach, 2010; Boucsein, 2011; Dawson et al., 2007).

To conduct our analysis, we applied the steps listed below to the raw data obtained from the sensor:

- First, raw data collected from the sensor was converted into SC values in micro Siemens (µS). Then, the converted SC was imported into Ledalab software (Benedek and Kaernbach, 2010, Ledalab V3.4.3, 2012).
- Data was preprocessed to ensure more effective analysis (it was down-sampled by gauss and factor 6 to 17.07Hz from the original 102.4Hz).
- To detect SCR, the Continuous Decomposition Analysis method (CDA) was used to decompose SC data into continuous tonic (SCL) and discrete phasic activity (SCR) (see Figure 4). This method is comparatively fast and robust.
- The analysis was optimized by the use of a second run of CDA.
- The resulting analysis was applied to the original data (by a process called reconstruction).

The export and matching of SC data with device operations included:

- Based on the minimal threshold of 0.01 µS (Benedek and Kaernbach, 2010), the detected SCR were exported as a list that indicated the starting time and amplitude of the individual SCR.

- For all subjects, we considered an average delay of onset of three seconds (Dawson et al., 2007) for the peaks of SCR from each particular operation (as stimulus). Thus, the SCR list was divided into corresponding operations for each device (e.g., detected SCR during operations performed on the air conditioner).
- The parameters of SC and SCR were then calculated for 36 cases by subject, vehicle, and device. We considered the entire period for each operation and each particular device (e.g., from the start of the operation on the navigation system to its end).

Table 1 shows descriptive statistics related to the calculated SC parameters and subjects' provided evaluations. Next, a correlation analysis was performed to discover whether a common tendency could be found between the calculated parameters and the subjects' provided evaluations. The results of the observed correlations are shown in Figure 6. The correlation values and their significance are indicated in Table 2.

Table 1. Descriptive statistics related to the SC parameters and subjects' provided evaluations based on the Uncomfortable – Comfortable Scale included in the questionnaire.

	SC parameter	SCR parameters			Uncomfortable - Comfortable (1 to 7)
	$\bar{x}_{LogSC}$	$\bar{x}_{LogSCR}$	Σ_{LogSCR}	ω_{SCR}	
Average	0.570	0.038	6.161	0.397	4.167
SD	0.248	0.022	4.926	0.231	1.067
Cases: n	36	36	36	36	36

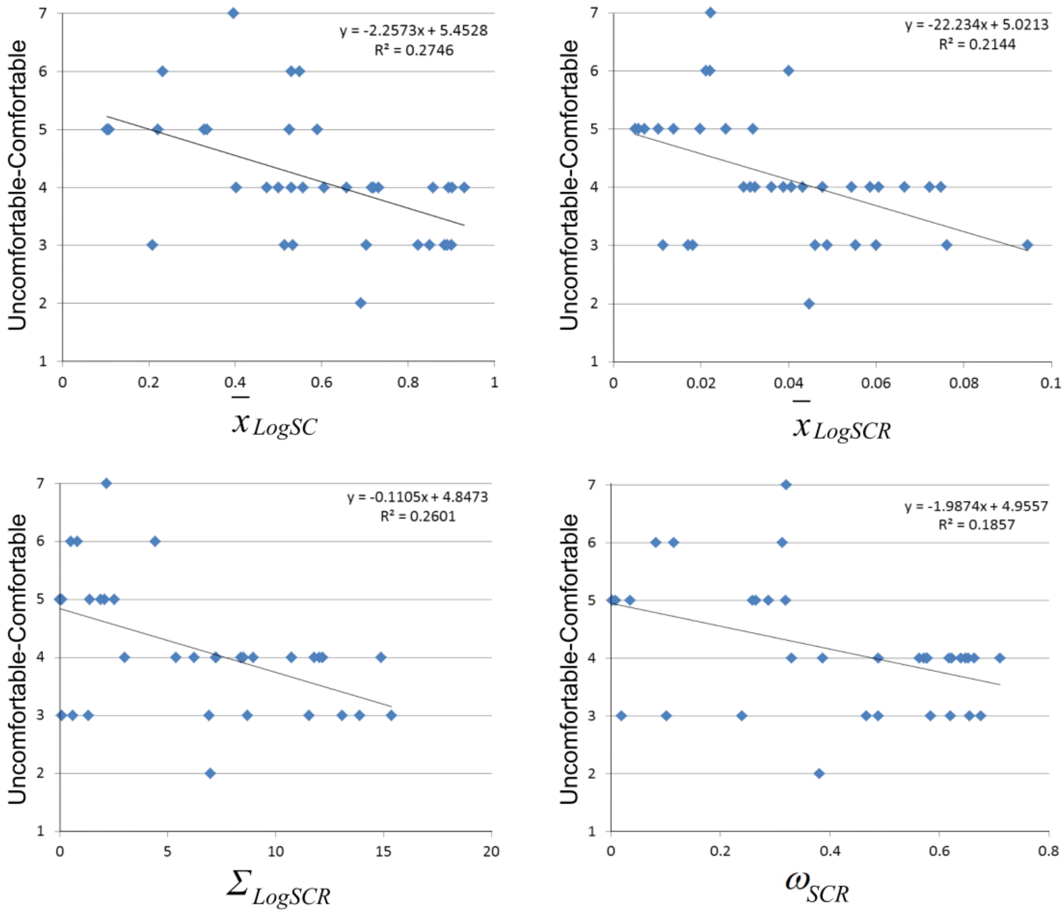

Figure 6. Plots of correlations.

Table 2. Correlations of SC and SCR parameters with explicit evaluation scale Uncomfortable – Comfortable (Cases: n=36, all significant at level p<0.01).

	SC parameter	SCR parameters		
	$\bar{x}_{LogSC}$	$\bar{x}_{LogSCR}$	Σ_{LogSCR}	ω_{SCR}
Correlation coefficients	–0.524	–0.463	–0.510	–0.431
Significance level	0.001	0.004	0.001	0.009

6 DISCUSSION

6.1 General discussion

In this study, we attempted to capture comfort during subjects' unrestricted operation of devices installed in vehicles by the use of SC biosignal. Based on the results of our experiment, we compared a set of quantitative parameters of SC to conventional evaluations of comfort that were collected by the use of a questionnaire.

The results were compared on the basis of the hypothesized connection between evaluations based on the Uncomfortable – Comfortable Scale and on SC parameters. The observed correlations indicate a common tendency between these parameters and subjects' evaluations—the lower the SC parameters are, the higher are the evaluations for comfort. The results were also congruent with previous studies (Shi et al., 2007, Tomico et al., 2008).

In particular, the two main contributions of this study are listed below:

- We investigated comfort by capturing SC during subjects' free and unrestricted operation of particular devices installed in vehicles. We attempted to provide an environment that allowed operation that simulated, as closely as possible, an everyday interface operation.
- Based on the results of previous studies, we extracted and analyzed quantitative parameters of SC that might be effectively applied to evaluate comfort. This analysis was based on rigorous methods of analysis of SC data and on the latest developments in the area.

The results reveal that this approach can be useful for the evaluation of comfort. In addition, the evaluation of comfort through the use of SC capture can aid comparisons of comfort during different device operations. In this respect, the method is relevant for identifying designs that can essentially provide better comfort of operation.

In general, the method can be employed to comparatively evaluate designs for comfort in different settings. However, in order to obtain data that are sizeable enough for comparison, the method may be most applicable only in settings in which the user is actively engaged in operation or interaction with the product or its interface.

In a previous study, we proposed a method that could be used to identify human comfort during interface operations based on inexplicit indicators of comfort. This was performed by the use of a protocol analysis of free verbalizations and an associative concept network analysis of those verbalizations (Georgiev et al., 2012b). That method allowed quantification of elements of comfort based on an in-depth analysis. The investigation of SC discussed in this current study complements an elaborated evaluation of comfort. It also allows further comparison of comfort during different device operations.

Because comfort is perceived by humans in an interior manner, they can struggle to capture and express these perceptions. In this study, we captured the element of comfort independently from the human expression of comfort. Comfort that humans experience during interface operation depends on their inner senses. Thus, it is related to human sensitivity and human motivation to design (Taura and Nagai, 2011).

6.2 Specific discussion

The parameters $\bar{x}_{LogSC}$, $\bar{x}_{LogSCR}$, and Σ_{LogSCR} are connected with the total amounts of SC and SCR. They quantify the degrees of response of SC. Thus, degrees of response probably quantify comfort during interface operations. However, further research is required to clarify the connection that exists between degrees of response and comfort, particularly with respect to terms of SCR during time and sensitivity events as suggested in previous research (Georgiev et al., 2012a).

The experimentally-obtained and calculated parameters of SC exhibit a common tendency with the explicit evaluations subjects provided on the Uncomfortable – Comfortable Scale. Furthermore, the amount of variance explained is not high because these two independent measures (SC data and SD evaluation) were the subjects of different errors.

6.3 Limitations of the study

The study's limitations are listed below:

- Only a limited number of subjects were used in the study (a total of 36 cases provided by 6 subjects).
- Only a limited number of different devices and vehicles were used during the study. Furthermore, a possibility exists that one device operation performed in the same vehicle may have been influenced by another device operation.
- The SC data may have been influenced by the amount of subjects' verbalizations.
- SC has limitations as a data resource with respect to variability. For example, changes in SC data do not occur in isolation. However, the strict experimental conditions enforced in this study helped minimize that aspect of this limitation. For example, although they were reduced by the applied logarithmic transformations in this research, the individual differences in SC can also be considered limitations of the approach.

Finally, this approach is applicable in cases that require comparisons of device operations, products, and so on. However, with respect to single subjects or constant groups of subjects, this approach cannot be applied as an absolute evaluation value because values are not comparable across subjects.

6.4 Suggestions for further research

In the future, we hope to analyze the issues discussed in section 6.3, Limitations of the Study. In particular, we hope to examine the relationship that may exist between the amount of verbalization and SC data.

In the conduct of a large-scale experiment, we believe the next step in our research would involve extensive evaluation of comfort. Free and unrestricted human speech is a common, naturally-occurring process during interface operation. It can provide an indication of the nature of human sensitivity. We hope to use elaborated SC data analysis and an in-depth analysis of free verbalizations produced during interface operations to quantify human comfort during operation in a more systematic manner. Our future work will focus on qualitative analysis of comfort and, particularly, on interface operation events related to comfort. Our intention is to employ this approach to comfort in an integral investigation of human sensitivity during vehicle operation.

7 CONCLUSIONS

In this study, we investigated a quantitative evaluation of comfort. We attempted to capture comfort during-the-operation as subjects operated a vehicle interface. We investigated human comfort by the use of biosignal of Skin Conductance (SC) during subjects' free and unrestricted operation of devices installed in vehicles. The extracted quantitative parameters of SC can be applied to evaluate comfort. We quantified comfort in a systematic and rigorous way.

SC provides an unaltered and continuous indicator that can be used to evaluate overall comfort. It can also be used to identify particular comfort issues that arise during interface operation. The evaluation of comfort relies on a psycho-physiological indicator of SC that provides an essential contribution to user experience design and design for emotion. The provision of comfortable user experiences is a core element of design. It must coordinate products with users' inner sensitivity in order to create a sense of harmony between products and users.

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