Use of a multidimensional approach in the automotive product development: Quality of turn indicator sounds

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Abstract

In the automotive industries, it becomes more and more important to connect customer requirements and technical specifications to develop sounds with high quality. The turn indicator sound can be heard very often during drives and gives the customer important feedback on correct function performance. Thus, this is one of the sounds, which play a role in the customer's perception of vehicle quality and which is safety relevant as well. In an experimental laboratory study the question was investigated, how a turn indicator sound must be designed to be perceived as a high-quality and pleasant. A multidimensional approach was chosen to combine subjective assessments, physiological measures of the cardiovascular and the electrodermal activity and physical parameters of the sounds. In total, 15 different turn indicator sounds were assessed by 48 participants. The results show that high-quality turn indicator sounds are characterized by the fact that they are rather gentle, soft, reserved and not too rough and sharp. This can be confirmed by the physiological reactions of the participants. The study shows how the connection of subjective and objective parameters can support product development. Also, it shows a possibility to involve the human factor in a highly technical environment.

Introduction

Recent developments show that the subjective perception of a product and its sound cannot only be described by technical parameters (Genuit et al., 2006). Therefore it becomes more and more important to connect customer requirements and technical specifications (Resch & Mast, 2006). Especially in the automotive industry, where product sound can be seen as a differentiating factor between different brands these connections play an important role (Fastl, 2005; Nor et al., 2008; Otto & Wakefield, 1993; Schifferstein, 2006). Previous research has shown that customers believe instinctively that a high-class product also produces high-quality sounds (Miśkiewicz & Letoweski, 1999; Schulte-Fortkamp et al., 2007). On the other hand, the sound quality of a product can influence the perceived quality of a product (Genuit, 2008).

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Turn indicator sound

The turn indicator sound can be described as an operational vehicle sound with signalling character (c.f. Cerrato, 2009; Mühlstedt et al., 2007; Zeller, 2009). The acoustic feedback shows the driver that the indicator is set even if he does not see the visual information. Because of that the driver does not have to avert his gaze from the street if the traffic situation would not allow it. The turn indicator sound is also one of these sounds that a driver will hear very often during a drive. If it is not created well, it can become aversive for the driver. So it seems to be important to pay great attention on the development of this operational sound.

From a customer's point of view, the turn indicator sound can also be seen as one perceptible aspect that gives customers some information about vehicle quality. Vehicle manufacturers can design a brand specific sound and use it as distinguishing aspect (Bronner, 2007; Kilian, 2007; Krugmann & Langeslag, 2007; Zeller, 2009). Empirical data indicate that the turn indicator sound can be seen as one important representative sound for vehicle interior sounds. This sound also plays an important role for perceived customer's vehicle quality and was pointed out as a sound that polarizes with reference to customer's assessment (cf. Beitz et al., 2010). Based on the results of studies, improvement opportunities in three dimensions of vehicle sound perception "timbre", "loudness" and "roughness/sharpness" are found (cf. Wagner et al., 2009).

Multidimensional approach

The multidimensional impressions, which a product and its sounds may activate in a customer, call for a multidimensional approach to assess the sound quality of the turn indicator. The subjective assessment of the impression of driving, analyses of sounds as well as of noise is described as multidimensional in the literature (Alt & Jochum, 2003; Bodden, 1997; Genuit, 2002; Genuit & Burkhard, 1995; Schulte-Fortkamp, 2010). Genuit and Burkhard (1995) as well as Bodden (1997) claim that different parameters should be taken in consideration for sound evaluation: subjective parameters (psychological part) and objective parameters (physical and psychoacoustic part). A third approach includes psychophysiological measures to assess activation and emotional reactions in addition to subjective customer's assessments. This way of product testing has been used successfully for products which address other senses than the sense of hearing (Boucsein, 2007; Boucsein et al., 2002).

Physiological parameters

Human behaviour as well as cognitive, emotional and social phenomena are accompanied by physiological processes in different physiological systems. These processes can be made visible and measurable with the help of psychophysiological parameters. For emotional tone and activation/arousal parameters of the autonomic nervous system (ANS) are widely used (Boucsein & Backs, 2009). Cardiovascular and electrodermal activity was recorded in the present study. Psychophysiological measurements are not under active control of humans during normal conditions (Boucsein & Backs, 2009) and they are relatively easy to measure using noninvasive measurement techniques (Boucsein, 2006). It is well-known that noise produces different physiological responses which are quite similar to stress-responses, (Babisch, 2002, 2005; Griefahn & di Nisi, 1992; Ising & Kruppa, 2001; Ising et al., 1990) but these aspects should not be part of the present study. The interest lies in physiological response differences which correspond to subjectively assess sound qualities and the impression of pleasantness. An investigation of Bradley and Lang (2000) with different sounds showed that the subjective classification of the sounds in the two dimensions “pleasure” and “arousal” is accompanied by different physiological responses of the participants. Similar results are also shown with the help of investigations in the area of music (Iwanaga & Moroki, 1999; Sammler et al., 2007), traffic sounds (Raggam et al., 2007) as well as with everyday sounds (Gomez und Danuser, 2004). Investigations with other products than vehicles and their sounds showed that it is possible to make emotional experience with a product objectively measurable with the help of physiological measures (Boucsein, 2006; Mandryk & Atkins, 2007). The results of the different research groups agree that more than one single physiological measure is necessary to reflect the different psychophysiological processes of activation, emotions and attention in (sound) perception wherefore a combination of different measures is recommended (Boucsein & Ottmann, 1996; Whang, 2008).

Acoustic and psychoacoustic parameters

Different acoustic and psychoacoustic parameters should be adopted as objective measures in the present study. To cope with the circumstances that a sound as well as its subjective impression cannot be described well by using a single parameter, different parameters were considered in this study. Sounds with strong characteristics in the psychoacoustic parameter sharpness are often assessed as unpleasant, annoying and aggressive (Fastl, 2005; Fastl & Zwicker, 2007; Genuit, 2008; Maschke & Jakob, 2010). At the same time a product sound gets a strong and powerful character if the parameter sharpness is well-balanced (Fastl, 2005). In addition, the parameter loudness is able to influence the perceived quality and the perceived pleasantness of a product sound (Fastl, 1997, 2005; Fastl & Zwicker, 2007; Griefahn & di Nisi, 1992). Strong correlations between the perceived quality of engine sounds and the psychoacoustic parameter impulsiveness are also reported (Hashimoto, 2000).

Aim of the study

The study addresses characteristics which customer assign to a high quality turn indicator sound. Also, the importance of different dimensions of sound perception and the influence of differences due to age and gender are addressed in the present study. A multidimensional approach which combines subjective assessments of the participants as well as psychophysiological measures and physical characteristics of the turn indicator sounds were systematically included in the study.

Method

A laboratory experiment with repeated measurement was chosen for this study. During the experiment the participants were sitting in a sound-isolated acoustical cabin. The sounds were presented via headphones.

Sample

In total, data from 48 participants with normal hearing ability were incorporated in the study. Age and gender of the participants were balanced (male/female, < 35 years old/35 years old and older). The 48 participants were between 21 and 60 years old with an average age of 36.2 years (*SD* = 11.56). All participants owned a valid driver's licence and drove regularly.

Materials

In total, 15 different turn indicator sounds were assessed by the participants. Two different lengths of sounds were used in the laboratory experiment. A preliminary investigation with city drives and drives on motorways shows that in average the short sound has to have a length of three to five seconds. Because of this a sound length of four seconds was used. To assess the different sounds, a second lengths of sounds (30 seconds with an on/off-pattern of four seconds) was used: these second lengths of sounds consider that drivers normally hear the turn indicator sound in different situations: for example, it can be heard for a short time during an overtaking manoeuvre or if the driver changes lane, or for a longer time, when the driver wants to turn (e.g. crossroads, traffic light). The preliminary investigation results show as well that during a turning manoeuvre the turn indicator sound was heard by a minimum of 20 seconds, mostly even much longer. Based on these results it was decided to use trials with the parts: short sound period (4 sec.) – pause (10 sec.) – long sound period (30 sec.) for each sound in the second part of the experiment where the participants had to assess each sound. The sequences of the different sounds were randomly assigned.

The questionnaire comprised a broad range of items (7-point rating scales and items based on semantic differentials) addressing different aspects of participant's evaluations of the turn indicator sounds, items to assess these sounds including items of vehicle sound perception dimensions (cf. Wagner et al., 2009) and also items to specify the emotions and somatic feelings of the participants during the experiment.

Procedure

At the beginning of the experiment, each participant had to render an audiometry to check the hearing abilities of the sample. Only participants with normal hearing abilities were included into the final sample. After a short questionnaire (socio-demographic data and general attitude towards vehicle sounds), the electrodes for the physiological measurement were fixed. After baseline-recordings, all 15 turn indicator sounds (4 s.) were played to show the participants the evaluation framework of the experiment. After a 90 second psychophysiological recording, the turn indicator sounds were presented (4 s. – 10 s. pause – 30 s.) in groups of five sounds, each group followed by a psychophysiological recording (90 s.). When the participant finished the assessment of all 15 sounds a follow-up survey had to be filled out. The psychophysiological recordings took place during rest intervals and during the sound presentations.

Physiological measurement

The physiological recordings were conducted with the varioport system from Becker Meditec. The participants wear the portable recorder in the acoustical cabin during the experiment to record loggings of the trigger as well as cardiovascular (ECG) and electrodermal activity (EDA). ECG was recorded using a thorax lead. EDA was recorded as skin conductance from the inner palm (thenar and hypothenar) of the non dominant hand of the participants (two Ag/Ag-Cl-electrodes filled with 0.5% NaCl paste, diameter = 22 mm; recordings: 0.5 V constant voltages, resolution = 0.002 μS).

The software variograf was used to convert the data. For the elimination of artifacts and the computation of the different measures, different software packages from Boucsein's laboratory were used (Schaefer, 1999, 2000, 2002, 2005). The measures which were used in the statistical analyses were for ECG: heart rate (HR) in beat per minute (bpm) and heart rate variability (HRV) calculated as mean square of successive differences (MQSD) and for EDA: Level EDL, non-specific skin conductance response (NS.SCR), sum-amplitude and mean sum-amplitude. A baseline correction has been done for all measured physiological values. For every physiological measure, two mean values were calculated from the measurements during the trials (short sound period – pause – long sound period) to analyze the physiological effects of each of the turn indicator sounds: one mean value for the 10 seconds of the pause after hearing the short sound and one mean value for the 30 seconds while the participants are listening to the so called long sound.

Sound analysis

The software ArtemiS was used to analyze all 15 turn indicator sounds. All analyzed sounds were binaural recordings of the turn indicator sounds, recorded with an artificial head from HEAD acoustics in the original experimental setting. In this study, different acoustic parameters were used: A-rated sound pressure level [dB(A)], specific loudness [soneGD] (DIN 45631), sharpness [acum] (DIN 45692) and specific impulsiveness [iu]. All parameters represented an average value over each turn indicator sound signal (two-tone-unit).

Statistical analysis

Analyses of variance and regression analyses were performed for calculating the results. A significance level of 5 % was adopted for the results. Due to a descriptive approach no α-correction was conducted (Abt, 1987). The statistical analyses of the data were conducted using the software SPSS 17.0 for Windows.

Results

Perceived quality differences of the turn indicator sounds

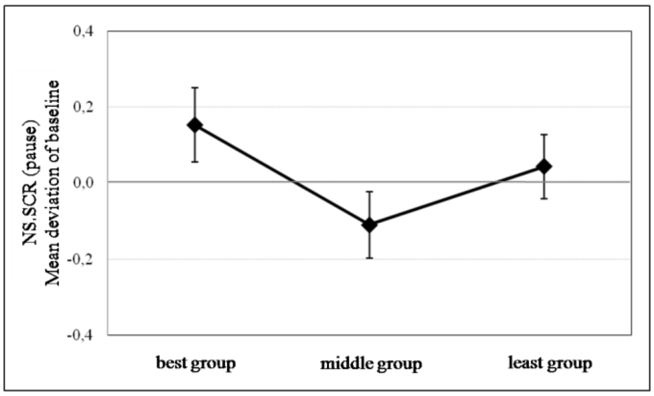
Based on the results of an analysis of variance with repeated measures three sound groups of significantly differing quality ratings (quality, comfortable/pleasantness) could be formed: best rated group (5 sounds), middle rated group (5 sounds) and least rated group (5 sounds), $F(1.73, 81.22) = 101.64$, $p < .0001$.

Differential effects

No significant differences for the independent variables age (2 groups), $F(1, 44) < 1$, *ns*, and gender (2 groups), $F(1, 44) < 1$, *ns*, as well as for their interaction age x gender, $F(1, 44) = 1.49$, *ns*, can be shown for the factor quality sound groups (3 groups: best, middle, and least assessed).

Psychophysiological measures

Results of the analyses of the physiological parameters and the factor quality sound groups only show significant differences for the electrodermal parameter NS.SCR during the pause between hearing the short and the long sound, $F(2, 43) = 7.03$, $p = .002$ (see figure 1).



Note. Error bars reflect Std. Error of Mean; 0.0 = Baseline level

Figure 1. Differences in electrodermal response for the three quality sound groups

Post-Hoc analyses show significant differences between the electrodermal response during best and middle assessed group (Sidak, $p = .002$), a tendency between middle and least assessed group (Sidak, $p = .053$) and no statistical significant differences between best and least assessed turn indicator group.

The adding of the two independent parameters age and gender into the analyses show a significant main effect of age groups with the cardiovascular parameter HRV (MQSD, heart rate variability) during the pause period, $F(1, 44) = 4.91$, $p = .032$. Older participants react less aroused/distracted (higher HRV) on the different turn indicator sounds than younger participants. Additionally a significant interaction between age and gender, $F(1, 44) = 3.95$, $p = .053$, can be shown with the cardiovascular parameter HRV (MQSD) during the sound period. Younger women react stronger and less relaxed on the different turn indicator sounds than older women and men. Overall, the strongest reactions can be shown for sounds of the least rated sound group. Significant effects with other psychophysiological measures cannot be shown.

Dimensions of sound perception

The mean values for each of the three dimensions “timbre”, “loudness” and “roughness/sharpness” were calculated as our former research shows that both requirements and assessments of vehicle sounds can be represented using these vehicle sound perception dimensions (Wagner et al., 2009). A regression analysis with these three dimensions as regressors and the quality rating score as dependent variable shows that for turn indicator sounds the dimension “timbre” is not significantly related to the quality rating score. In addition, the dimension “loudness” is negatively related and the dimension “roughness/sharpness” is positively related to the quality rating score. So, a high-quality turn indicator sound is characterized by the fact that it is rather gentle, soft and reserved as well as not too rough and sharp. The values of the regression analysis can be seen in table 1.

Table 1. Linear regression analysis for the dimensions predicting the quality rating score

Variable	B	SE B	β
Timbre	-.069	.039	-.054 *ns*
Loudness	-.758	.040	-.636**
Roughness/sharpness	.085	.036	.074*

Note. Adj. $R^2 = .495$. $^{**}p < .0001$, $^{*}p < .05$.

To enable a closer look into the three dimensions of vehicle sound perception and their varieties for the analyzed turn indicator sounds, analyses of variance with repeated measures were calculated based on the subjective assessments in each dimension. These analyses show that the 15 different turn indicator sounds can be assorted into different groups on the basis of their different subjective assessments in each dimension. Multivariate analyses of variance validate the significant differences between the formed groups. The turn indicator sounds were grouped into three significant different assessed groups in the dimension “loudness”, $F(8.37, 393.24) = 22.73$, $p < .0001$, into three significant different groups because of their assessment in the dimension “roughness/sharpness”, $F(9.52, 447.27) = 10.24$, $p < .0001$, and have to be arranged into four significant different assessed groups with reference to the dimension “timbre”, $F(8.98, 422.08) = 37.97$, $p < .0001$. Although the regression analyses shows no significant relevance ($p = .076$) of the dimension “timbre” with regard to the quality rating score, it was included in the following analyses to clear coherences with other measures and this dimension.

Differential effects

Neither for the three different assessed groups in the dimensions “loudness” and “roughness/sharpness”, nor for the four different groups of the dimension “timbre”, significant differences because of age or gender can be shown.

Psychophysiological measures

Significant effects for the different groups of vehicle sound perception on physiological parameters could be show in a repeated measurement MANOVA. Results are shown in table 2.

Table 2. Significant psychophysiological reactions on subjective assessments in the different dimensions of vehicle sound perception

Dimension	Physiological Parameter	*F*	df	*p*
Loudness (3 groups)	Cardiovascular activity:			
	HRV (MQSD) pause period	3.49	2/43	.039
	HRV (MQSD) during sound	6.19	1.75/76.82	.005
Roughness/	Electrodermal activity:			
Sharpness (3 groups)	NS.SCR during sound	3.31	1.74/76.48	.048
Timbre (4 groups)	Cardiovascular activity:			
	HRV (MQSD) pause period	7.87	1.87/82.44	.001
	HRV (MQSD) during sound	5.07	1.53/67.30	.015

For “loudness” and “timbre”, significant cardiovascular reactions can be found while “roughness/sharpness” affects electrodermal activity selectively. Post-hoc analyses show that the subjectively sensed richest, darkest and low pitched sounds (dimension “timbre”) bind least attention and result in fewer arousal/distraction and at the same time are more pleasant than other turn indicator sounds. If a sounds perception is not reserved, gentle and soft (dimension “loudness”), the level of relaxation of the participants decrease. Furthermore, very sharp and rough perceived turn indicator sounds call for more attention, is more distracting and result in larger emotional arousal than other sounds.

Acoustic parameters and subjective sound perception

To clarify connections between the acoustic parameters and the perceived quality of the analyzed turn indicator sounds, a regression analysis with all acoustic parameters as regressors and the quality rating score as dependent variable has been carried out. Because of the relatively strong correlation ($r = .752$, $p = .001$) between the two volume related parameters specific loudness and A-rated sound pressure level [dB(A)], two separate regression analyses – one with specific loudness, sharpness and specific impulsiveness and one with A-rated sound pressure level [dB(A)], sharpness and specific impulsiveness were carried out. The results of these two analyses show, that specific loudness results in a better prediction. Specific loudness and sharpness are negatively related to the quality rating score. This means that a turn indicator sound which produces a perception of high quality should be physically characterized by lower values in specific loudness and sharpness. The values of the analyses can be seen in table 3.

Table 3. Regression analyses for acoustic parameters predicting the quality rating score

Variable	B	SE B	β
Regression analysis 1			
A-rated sound pressure level [dB(A)]	-.198	.068	-.630*
Sharpness	-.266	1.083	-.051 *ns*
Specific impulsiveness	-.078	.075	-.238 *ns*
Regression analysis 2			
Specific loudness	-.248	.063	-.856**
Sharpness	-2.431	1.028	-.471*
Specific Impulsiveness	-.069	.063	-.212 *ns*

Note. Regression analysis 1: Adj. $R^2 = .450$. $^{**}p < .01$, $^{*}p < .05$
Regression analysis 2: Adj. $R^2 = .602$. $^{**}p < .01$, $^{*}p < .05$

Discussion

The concentration on a specific source of sound allows a detailed investigation of the customer’s reactions on differently sounding turn indicators using a multidimensional approach. The absence of significant perceived quality differences due to age or gender supports the idea of the implementation of a brand sound of the turn signal against a differential approach which considers varying target groups of different vehicle segments. Because of the frequent usage of the turn indicator during normal drive situations, the application of one corporate turn indicator sound into all vehicles of different segments of a company can also be used as additional and easy recognizable item to strengthen brand identity. As well the integration of the results of the physiological measurements supports this recommendation. The results show that due to differences in the perceived quality of the evaluated 15 turn indicator sounds three different groups can be formed (best, middle, least rated group), which can be characterized by different electrodermal and cardiovascular responses. The turn indicator sounds of the middle rated group do not activate emotions as strong as turn indicator sounds which belong to the best or least quality group. Even older participants react less aroused on the different sounds. From a physiological point of view turn indicator sounds of the best rated perceived quality group should be implemented to reach positive emotions of the driver and at the same time prevent mental workload. Sounds which belong to the middle rated group can be used if the intention is to implement a sound which remains in the background. The results advise against the implementation of turn indicator sounds of the least rated group not only because of their poorer values in the perceived quality, but also because these potentially trigger arousal in the direction of negative emotions.

The regression analyses with the acoustic parameters supports the suggestion that a turn indicator sound which produces a perception of high quality can physically be characterized by lower values in the volume related parameters A-rated sound pressure level [dB(A)] and specific loudness. In addition, especially in the combination with specific loudness, the parameter sharpness should be less pronounced. These results correspond with results from Fastl (1997, 2005) and Fastl and Zwicker (2007) who assume that loudness is able to influence the perceived quality of a product sound. Fastl (2005) proposes furthermore a well-balance of sharpness. On the other hand, the importance of specific impulsiveness for perceived sound quality which Hashimoto (2000) reports for engine sounds could not be verified for turn indicator sounds in the present study.

The inclusion of the dimensions of vehicle sound perception (c.f. Wagner et al., 2009) allows deriving recommendations for future sound developments. The regression analyses with the three dimensions of vehicle sound perception show that a high-quality turn indicator sound is rather gentle, soft and reserved as well as not too rough and sharp. This result is supported by the physiological reactions of the participants that show that if the perception of a turn indicator sound is not reserved, gentle and soft, the level of relaxation of the participants decrease. Too sharp and rough perceived turn indicator sounds call for more attention of the listener and result in stronger emotional arousal. The physiological measures support, that subjectively sensed rich, dark and low pitched turn indicator sounds are most pleasant, bind least attention and result in fewer arousal/distraction than other sounds.

To sum up, the results of this study show that a multidimensional approach which brings together different subjective and objective aspects of a sound and its perception, can be seen as an important step to determine further optimization options for the development of high-quality sounds.

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