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Sound Quality of Turn Indicator Sounds—Use of a Multidimensional Approach in the Automotive Product Development

Verena Wagner and Konrad Wolfgang Kallus

Department of Psychology, Work, Organizational and Environmental Psychology, University of Graz, Graz 8010, Austria

Abstract: Vehicle sounds are important factors of customer satisfaction and have a decisive influence on the product automobile and its quality impression. It becomes more and more important to connect customer requirements and technical specifications to develop a vehicle sound with high quality. The turn indicator sound can be described as one sound, which gives the customer an important feedback of correct function performance and can be seen as one of the sounds, which play a role in the customer's perception of vehicle quality. In a laboratory experimental study, the question was investigated, how a turn indicator sound must be designed to be perceived as pleasant and high-quality. A multidimensional approach was chosen to combine subjective customer assessments, objective psychophysiological responses of the study participants and physical parameters of the sounds. In total, 15 different turn indicator sounds were assessed by 48 subjects. The study shows how the connection of subjective and objective parameters can support product development. The multi-dimensional approach helps to derive recommendations for action to improve the sound quality of the product automobile. Also, the study shows a possibility to involve the human factor in a highly technical environment.

Key words: Vehicle sound quality, multi-dimensional approach, experimental study, customer requirements, technical specifications.

1. Introduction

In the automotive industry, product sound can be seen as one differentiating factor between different brands that can influence customer satisfaction and the perceived overall product quality [1, 2].

The turn indicator sound is one of the in-vehicle sounds which can be heard very often while driving. Also, it is important for the perceived customer's vehicle quality [3]. Therefore, it is necessary to pay attention to the quality of this sound. In addition, the turn indicator sound, which can be described as operational sound with signaling character [4-6], gives the driver an important feedback about the correct function performance of the turn indicator. This acoustic feedback helps the driver to keep his eyes on the road due to no need in seeing the visual information which is shown in the cluster display.

A difficulty for the development of high-quality vehicle sounds lies in the fact that it is not possible to describe subjective product sound perception only by technical parameters [7]. Therefore, it becomes more and more important to bring together customer requirements and assessments, and technical specifications [8]. To cope with the multidimensional impression that a product/vehicle sound may activate in a customer, a multidimensional approach should be chosen for product testing and sound assessments. The multidimensional approach combines subjective parameters (psychological part), objective parameters (physical and psychoacoustic part), and psychophysiological measures (activation and emotional reactions) [9-12]. This approach also corresponds to the results of other research groups that describe the assessment of driving as well as analyses

Corresponding author: Verena Wagner, Dr., research fields: sound perception and sound design, human factors in transportation, hearing impairment at (elderly) employees and psychophysiology in ergonomics. E-mail: verena.wagner@uni-graz.at.

of sounds and noises as multidimensional [9, 12-15].

1.1 Acoustic and Psychoacoustic Parameters

Because a sound and its subjective impression cannot be described well by using only one single parameter, different acoustic parameters were considered in the present study: sharpness, specific loudness, A-weighted SPL (sound pressure level) (dB(A)) and specific impulsiveness. The psychoacoustic parameter sharpness was chosen because sounds with a well-balanced proportion of sharpness are often assessed as strong and powerful [16], whereas strong characteristics of this parameter are often assessed as unpleasant, annoying and aggressive [1, 16-18]. Also, different studies show that the parameter loudness seems to have an influence on the perceived quality and the perceived pleasantness of a product sound [16, 17, 19, 20] and the parameter impulsiveness strongly correlates with the perceived quality of engine sounds [21].

1.2 Psychophysiological Parameters

Physiological parameters help to make physiological processes of different psychophysiological systems that accompany human behavior and cognitive, emotional and social phenomena, visible and measurable. Because of being actively non-controllable under normal conditions and the relatively easy assessment with non-invasive measurement techniques, parameters of the ANS (autonomic nervous system) are widely used to measure activation/arousal and emotion [22, 23]. Boucsein [22] and Mandryk and Atkins [24] successfully showed that emotional product experience is objectively measurable using psychophysiological measures. Investigations with different sounds show that the subjective assessment of sounds is accompanied by different psychophysiological reactions [25-29]. Measures of the cardiovascular and the electrodermal activity were recorded in the present study, to make physiological response differences visible, which correspond to subjectively assess sound qualities.

1.3 Aim of the Study

Due to a lack of available research results regarding the sound quality of turn indicator sounds, the purpose of the study presented in this paper was to investigate how a turn indicator sound must be designed to be perceived as pleasant and high-quality as well as which characteristics customers assign to high-quality turn indicator sounds. Therefore, a multidimensional approach which combines subjective assessments, psychophysiological measures and physical characteristics of the analyzed turn indicator sounds was systematically included in the study.

2. Method

2.1 Sample

Forty-eight subjects participated in this laboratory experiment. Gender and age of the participants were balanced (male/female, < 35 years old/35 years old and older). The participants were between 21 and 60 years old (mean age M = 36.2, SD (standard deviation) = 11.56) and had normal hearing abilities, a valid driver's license and drove regularly.

2.2 Materials, Measurements and Procedure

2.2.1 Turn Indicator Sounds

Overall, the participants assessed 15 different turn indicator sounds that were presented via headphones. Because of their origin/way of making, the 15 sounds can be arranged into three groups: real turn indicator sounds from actual vehicles (binaural recordings), non-synthesized generated turn indicator sounds (mixture of everyday life sounds) and synthesized generated sounds (designed square wave signals). Every group consists of five different turn indicator sounds. Based on a preliminary investigation, two different sound lengths presentation times were used in the laboratory experiment, respectively: a short sound period of 4 s length which represents situations like (fast) lane changes during city drives or on motorways and overtaking maneuvers, and a longer sound period of 30 s length that represents situations like turning maneuvers (e.g., crossroads and traffic light). Due to the fact that a turn indicator sound consists in its shortest form of one "two-tone-unit", a presentation time of 4 s (short sound period) is equivalent to six "two-tone-units". To assess the different turn indicator sounds, trials with both sound lengths were presented for each turn indicator sound: short sound period (4 s)—pause (10 s)—long sound period (30 s). The sequences of the 15 different sounds were randomly assigned.

For the statistical analyses, the binaural recordings (artificial head of HEAD acoustics, recorded in the original experimental setting) of the 15 turn indicator sounds were analyzed with the software Artemis. The different acoustic parameters used in this study are: A-weighted SPL (dB(A)), specific loudness (soneGD) [30], sharpness (acum) [31] and specific impulsiveness (iu). All parameters represented an average value over each turn indicator sound signal (two-tone-unit).

2.2.2 Questionnaire

The questionnaire consisted of a broad range of different items (7-point rating scales and semantic differentials, e.g., "quiet-loud") to address different aspects of participant's assessments of turn indicator sounds, items of vehicle sound perception dimensions [32, 33], items to survey socio-demographic data (e.g., age, gender and annual mileage), the emotional and somatic feeling during the experiment as well as the general attitude towards vehicle sounds (e.g., "A sound must match its sound source" [33]. The assessment (paper-pencil) of each sound takes place immediately after hearing the sound.

2.2.3 Physiological Measurement

The physiological measurement was recorded with the portable VARIOPORT system of Becker Meditec and took place during the sound presentation and during rest intervals. Cardiovascular activity (ECG (electrocardiogram)) was recorded using a thorax lead and EDA (electrodermal activity) 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 of 22 mm; recordings: 0.5 V constant voltages and resolution of 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 and 2005). The psychophysiological measures in the statistical analyses were for ECG: HR (heart rate) in bpm (beat per minute) and HRV (heart rate variability) calculated as MQSD (mean square of successive differences), and for EDA: SCL (skin conductance level), NS.SCR (count of non-specific skin conductance responses), sum-amplitude and mean sum-amplitude of SCR (skin conductance responses). A baseline correction has been done for all measured physiological values. To analyze the physiological effects of each of the turn indicator sounds, two mean values were calculated for each physiological measure recorded during the trials (short sound period-pause-long sound period): one mean value for the 10 s of the pause after hearing the short sound ("pause period") and one mean value for the 30 s while the participants are listening to the so called long sound ("during sound").

2.2.4 Procedure

The study was conducted as laboratory experiment (sound-isolated acoustical cabin) with repeated measures. After an audiometry check to ensure that only participants with normal hearing abilities were included in the study, the participants had to fill out a short questionnaire (socio-demographic data, general attitude towards vehicle sounds), the electrodes for the physiological measurement were fixed, the baseline-recordings take place and the 15 different turn indicator sounds were played in their short version of 4 s to show the participants the evaluation framework of the experiment. After a 90 s psychophysiological recording, the turn indicator sounds were presented (4 s—10 s pause—30 s; start of each sound presentation triggered by the participants by pushing a button that simulates activating the turn indicator; assessment immediately after hearing each sound) in groups of five sounds, each group followed by a psychophysiological recording (90 s). After the participant had assessed 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.

2.2.5 Statistical Analyses

Analyses of variance, regression and correlation 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 (alpha adjustment for multiple testing) was conducted [34].

3. Results

3.1 Perceived Sound Quality and Acoustic Parameters

To analyze connections between the perceived quality of the analyzed turn indicator sounds (quality rating score: mean value not at all/very high-quality, comfortable/pleasantness) and the different acoustic parameters (A-weighted SPL, specific loudness, sharpness, specific impulsiveness), two linear regression analyses were carried out. The decision to split the two volume related acoustic parameters specific loudness and A-weighted SPL (dB(A)) into two separate analyses was based on the relatively strong correlation between them (r (correlation coefficient) = 0.752, p (p-value) = 0.001). The results (Table 1) show that both volume related parameters as well as sharpness (only in combination with specific loudness) are negatively related to the quality rating score. A comparative glance at both regression analyses shows that the first analysis with specific loudness results in a better prediction (adjusted R^2 = 0.602) than the second analysis with A-weighted SPL (dB(A)) (adjusted R^2 = 0.450).

3.2 Perceived Sound Quality and Sound Origin/Ways of Making

To show possible subjective quality differences between the three sound groups, which can be formed, based on the three different ways of making (binaural recordings, non-synthesized generated sounds and synthesized generated sounds), an analysis of variance with repeated measures, with the mean values of quality rating score (mean value: not at all/very high-quality, comfortable/pleasantness) of each sound group as dependent variable, was performed. The result shows that there are no significant quality differences because of the making of the sounds, $F(2,46) = 2.68$, not statistically significant.

Results of analyses of variance with repeated measures of the recorded psychophysiological parameters and the different sound groups based on the sound origin only show that there are—with the exception of one parameter—also no significant differences between the psychophysiological reactions of the participants. The exception is the parameter sum-amplitude during sound, $F(2,46) = 4.18$, $p = 0.022$. Post-hoc analyses show significant differences between non-synthesized (M = -0.01, SD = 0.14) and synthesized generated (M = 0.04, SD = 0.14) sounds (post-hoc test: Sidak, p = 0.044) which means that non-synthesized generated sounds result in lower arousal than synthesized generated sounds.

Table 1 Linear regression analyses for acoustic parameters predicting the quality rating score.

Variable	*B*	*SE B*	β
Regression Analysis 1			
A-weighted SPL (dB(A))	-0.198	0.068	-0.630*
Sharpness	-0.266	1.083	-0.051 *ns*
Specific impulsiveness	-0.078	0.075	-0.238 *ns*
Regression Analysis 2			
Specific loudness	-0.248	0.063	-0.856**
Sharpness	-2.431	1.028	-0.471*
Specific impulsiveness	-0.069	0.063	-0.212 *ns*

B is estimated values of unstandardized regression coefficients, *SE B* is the standard error, β is the estimated values of standardized regression coefficients;
$^{**}p < 0.01$, $^{*}p < 0.05$.

3.3 Perceived Sound Quality and Dimensions of Sound Perception

Based on the findings of former research that customer requirements as well as customer assessments of vehicle sounds can be represented by using the three dimensions “timbre”, “loudness” and “roughness/sharpness” [32], the mean values for each of these dimensions were calculated. A regression analysis with the quality rating score as dependent variable and the three dimensions as regressors was analyzed.

The results show that the dimension “loudness” is negatively related, the dimension “timbre” tends to be negatively related and the dimension “roughness/sharpness” is positively related to the quality rating score (Table 2). Thus, a turn indicator sound with perceived high-quality is characterized by the fact that it is rather gentle, soft and reserved as well as not too rough and sharp.

In the next step, the 15 assessed turn indicator sounds were assorted into new groups based on the subjective assessments in each dimension of sound perception (analyses of variance with repeated measures). To validate the significant differences between the so formed groups, multivariate analyses of variance were performed for each dimension. So, the 15 turn indicator sounds that were assessed by the participants were grouped into three significant different assessed groups in the dimension “loudness”, into three significant different groups in the dimension “roughness/sharpness”, and into four significant different assessed groups in the dimension “timbre” (Table 3).

Analyses with repeated measures showed significant effects for the different groups of sound perception on the recorded psychophysiological reactions of the participants. Significant cardiovascular effects can be shown for the two dimensions “loudness” (HRV (MQSD) pause period: $F(2,43) = 3.49$, $p = 0.039$; HRV (MQSD) during sound: $F(1.75,76.82) = 6.19$, $p = 0.005$) and “timbre”

Table 2 Linear regression analysis for dimensions of sound perception predicting the quality rating score.

Dimension	*B*	*SE B*	*β*
Timbre	-0.069	0.039	-0.054*t*
Loudness	-0.758	0.040	-0.636**
Roughness/sharpness	0.085	0.036	0.074*

Adjusted $R^2 = 0.495$; $**p < 0.0001$; $*p < 0.05$, $t < 0.10$.

Table 3 Results of the multivariate analyses of variance.

Dimension	*F*	*df*	df_{Error}	*p*	Post-hoc test: Sidak *p*
Loudness	115.94	2	46	< 0.0001	< 0.0001
Roughness/ sharpness	37.15	2	46	< 0.0001	< 0.01
Timbre	181.75	3	45	< 0.0001	< 0.0001

(HRV (MQSD) pause period: $F(1.87,82.44) = 7.87$, $p = 0.001$; HRV (MQSD) during sound: $F(1.53,67.30) = 5.07$, $p = 0.015$), but not for the dimension “roughness/sharpness”. On the other hand, the results show that only the dimension “roughness/sharpness” affects electrodermal reactions of the participants while hearing the turn indicator sounds (NS.SCR during sound: $F(1.74,76.48) = 3.31$, $p = 0.048$). Based on post-hoc analyses, the results suggest that if a turn indicator sound is not perceived as reserved, gentle and soft (dimension “loudness”), the level of relaxation of the participants decreases. Furthermore, subjectively sensed richest, darkest and low pitched sounds (dimension “timbre”) bind least attention and result in lower arousal/fewer distraction and, at the same time, are more pleasant than other turn indicator sounds. Also, turn indicator sounds which are perceived as very sharp and rough call for more attention, are more distracting and result in larger emotional arousal than other sounds.

4. Discussions

Overall, the results of the study show that the concentration on one specific source of sound allows a detailed investigation of the customer’s reactions on differently sounding turn indicators using a multidimensional approach.

Bringing together the subjective perceived sound quality and the acoustic parameters of the analyzed sounds suggests that a turn indicator that is perceived as high-quality can physically be characterized by lower values in the volume related parameters: A-weighted SPL (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 former research results that loudness is able to influence the perceived quality of a product sound [16, 17, 19]. It should also be considered that high-intensity sounds or noise, especially with fast level rises can cause in psychophysiological stress responses [35]. Also, a well-balance of sharpness is recommended [16]. On the other hand, the importance of specific impulsiveness could not be verified for turn indicator sounds in the present study. Maybe the connection with this specific parameter is only valid for engine sounds [21] and not for other vehicle sounds. The comparison of the two analyses shows a better prediction of perceived sound quality by specific loudness and sharpness (Regression Analysis 2) than by using the parameter A-weighted SPL (Regression Analysis 1).

The assumption that differences in the perceived quality of the evaluated 15 turn indicator sounds do exist due to the three different origins/ways of making, cannot be verified. But the psychophysiological reactions of the participants show that, during hearing the different turn indicator sounds, non-synthesized generated sounds result in significant lower arousal than synthesized generated sounds. No significant reaction differences can be shown for sounds that are binaural recordings of turn indicator sounds of actual vehicles.

Not presented in the result section of this paper, but maybe interesting for the reader, based on these results, the idea comes up to build new groups of sounds based on their perceived quality ratings (best, middle and least rated group) [33, 36]. Each of these new groups consists of sounds of all three different origins (best rated sound group: two binaural recordings/two non-synthesized generated sounds/one synthesized generated sound; middle rated sound group: one binaural recording/two non-synthesized generated sounds/two synthesized generated sounds; least rated sound group: two binaural recordings/one non-synthesized generated sound/two synthesized generated sounds). From a physiological point of view, the results show that 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. Also, the implementation of turn indicator sounds of the best rated perceived quality group is suggested to reach positive emotions of the driver and, at the same time, prevent mental workload. Turn indicator sounds of the middle rated group can be used if the intention is to implement a sound which remains in the background. Furthermore, 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 sounds potentially trigger arousal in the direction of negative emotions.

The results for the different dimensions of vehicle sound perception “timbre”, “loudness” and “roughness/sharpness”, which were calculated based on former research results [32, 33], show that a turn indicator sound has to sound rather gentle, soft and reserved and not too rough and sharp to be perceived as high-quality sound by the participants. The psychophysiological reactions of the participants support this result. So, if a turn indicator sound is not perceived as reserved, gentle and soft, the level of relaxation of the participants decreases. Turn indicator sounds that are assessed as too sharp and rough call for more listeners’ attention, are therefore more distracting and result in stronger emotional arousal. Also, subjectively sensed rich, dark and low pitched turn indicator sounds are most pleasant, bind least attention and result in lower arousal/fewer distraction than other sounds.

5. Conclusions

To sum up, the results of this study show that the use of a multidimensional approach can be seen as important step to bring together different subjective and objective aspects of a sound and its perception. Therefore, it is recommended to think about using a multidimensional approach to determine further optimization options for the development of high-quality sounds.

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