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Characterization of next-generation car sounds

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ABSTRACT

Automotive companies are interested in understanding what attributes of naturally occurring, generated, and modified sounds make them more or less desirable to drivers and passengers. In this research, we investigated the perception of proposed next-generation car sounds and other sounds that could occur within a car interior or in other contexts. A pilot study was conducted to determine sound preferences when people were presented with the current sound, a very different sound, and something in between the two. Intentional sounds (e.g., turn indicators) and consequential sounds (e.g., car doors closing) were considered in four different contexts. Because of the focus on next-generation cars, responses from millennials (purchasers of cars over the next 40-50 years) are of particular interest. Compared to previous generations, millennials are more risk prone, adapt faster to new technologies, enjoy more interactive multimedia and prefer personalization and customization. The very different sounds are inspired by music preferences of the millennial generation (e.g. music and film). We also examined the influence of visual information and perceived functionality on those sound preferences. This research may shed light on how to integrate the generational differences of end-users into the design of future car sounds.

Keywords: Car sound evaluation, Millennials, Visual and auditory perception
I-INCE Classification of Subjects Number: 63.7

1. INTRODUCTION

Interior and exterior car sounds have been found to influence customers' evaluation of vehicles holistically, i.e. whether a car is luxury or cheap, sporty or economy and so on. For example, Filippou et al. (1) found that if the car door sound is tinny, the connotation is that the whole vehicle is cheap and not solid. In contrast, a full saturated sound of the closing of a cars door has a connotation of luxury. More related research can be found in (2, 3). To improve the quality of the sounds produced in cars, automotive companies are interested in understanding what attributes of naturally occurring, generated, and modified sounds make them more or less desirable to drivers and passengers.

The preferences of the purchasers of next-generation cars, millennials (born in 1980s to 2000), are of particular interest. Compared to the Baby Boomers (born in 1940s to 1950s) and Gen X (born in 1960s to 1970s), millennials are more fascinated by new technologies and adapt faster to computer and internet services (4, 5). Millennials enjoy interactive full motion multimedia, colorful images, and audio. Millennials prefer personalization and customization (5). Also, millennials are more risk prone than members of Generation X according to Reisenwitz and Iyer's study (6). All of these observations make it necessary to explore how we can integrate millennials' musical/sound preferences into the design of next-generation car sounds. Thus in this research, we primarily concern about: (i) how would millennials choose between traditional sounds and those modified, innovative sounds in the given car contexts? (ii) how would they evaluate these sounds?

Sound evaluation is a complex process and is influenced by information from multiple sensory channels. Many researchers have found that visual information can influence people's auditory perception. For example, in the study by Viollon et al. (7) on the influence of visual settings on sound ratings, they found that usually the more urban the visual setting, the more negative the sound ratings. This result is dependent on the type of sounds. Menzel et al. (8) found that exposure to some colors can increase or decrease loudness judgements. Colors like red or pink seem to cause an increase in loudness, grey or pale green were observed to decrease loudness. Yoshida et al. (9) presented luxury and sporty vehicle images to German or Japanese frequent drivers, while asking them to listen to the acceleration sounds. They found that German drivers tended to rate loudness lower and luxury higher

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when the sounds were presented with images of luxury cars, compared to images of sporty vehicles. Sportiness was rated higher when an image of a sporty vehicle was presented. These studies indicate that the perception of an event in one modality is influenced by information presented in another modality (10). Therefore in this research, we were also interested in: (iii) how pictorial or textual cues of the given contexts would impact the millennial subjects' sound perception?

To answer these questions, a pilot study was conducted to determine sound preferences when people were presented with the current sound, a very different sound, and something in between the two. Intentional sounds (e.g., turn indicators) and consequential sounds (e.g., car doors closing) were considered in four different car contexts. We also examined the influence of pictorial and textual information on those sound preferences and evaluations. This research may provide insights on how to integrate the generational differences of end-users into the design of future car sounds.

In the remainder of this paper, the test is described in Section 2, the preliminary test results are presented in Section 3 followed by discussions, and conclusions are given in Section 4.

2. DESCRIPTION OF TEST

To answer the three main questions given in Section 1, we designed a subjective test. In this section the overall structure of the test, the test sounds and playback method, the images and the subject demographics are described. The graphical user interface of the test was developed with Microsoft Visual C++ 2010.

2.1 Overall Structure

The test consisted of five parts, as illustrated in Fig. 1. In the first part, participants just listened to the 18 sounds used in the test without rating them. In Parts 2 and 3 subjects compared, rated and described sounds. In both of these parts they listened to sounds presented in six different contexts (three sounds were used for each context). Half the subjects did Part 2 (where images were presented) followed by Part 3 (context was described in words with no images) and half the subjects did Part 3 followed by Part 2. Details of these parts are given below. To avoid the impact of colors, monochromatic pictures were used in Part 2. In Part 4, subjects rated how much they liked the 18 sounds which were presented without context cues. At the end of the test subjects were asked to write comments on the test.

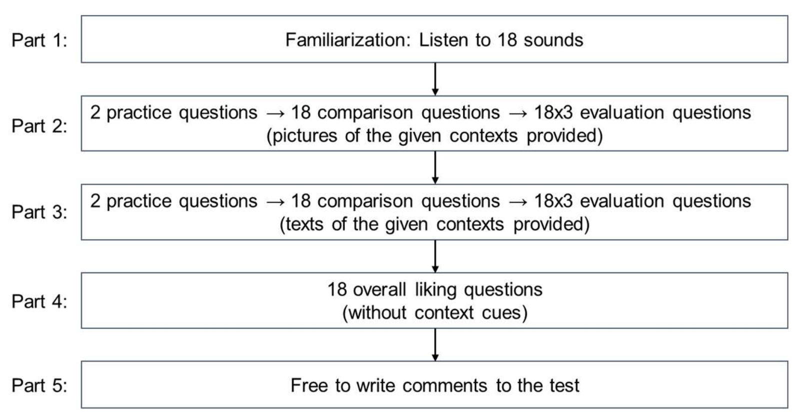
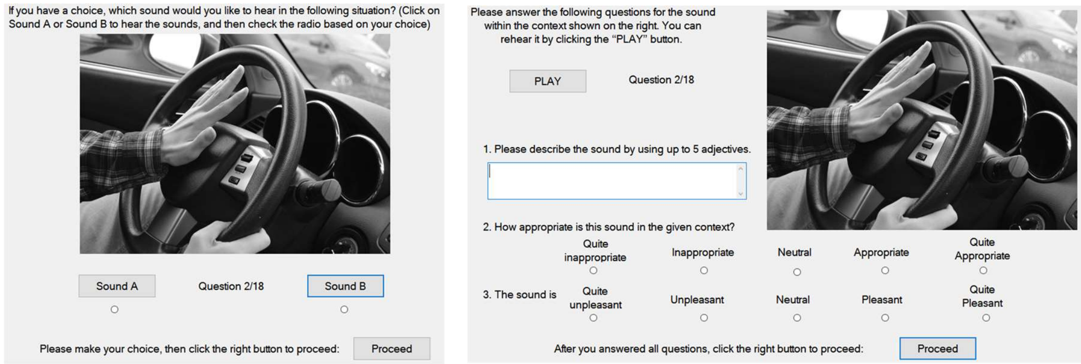


Figure 1 – The overall structure of the test.

In Part 2, participants first did two practice evaluations which consisted of choosing one of two sounds (comparison question) and then doing an evaluation of a sound. These two practice evaluations contained sounds and contexts that were not used after the practice session. Subjects then proceeded to do 18 comparisons, 3 per context. (Both AB and BA presentations were used to account for ordering effects.) The 18 context-sound pair groupings were presented in a different random order for each subject. Subjects were asked to respond to: "If you had a choice, which sound would you prefer to hear in the following situation?" Fig. 2(a) is an illustration of the interface that the subjects would see. On completion of the comparisons, they answered a set of three evaluation questions for each of the 18 sounds. Again context information was provided as shown in Fig. 2(b). Subjects were asked to: (a) describe the sound by using up to 5 adjectives, (b) indicate how appropriate is this sound in the given context? (c) indicate how pleasant they found sound? The appropriateness question provides five options to the participants, varying from “quite inappropriate”, “neutral” to “quite appropriate”. Similarly, participants can choose from five options for the pleasantness question, varying from “quite unpleasant”, “neutral” to “quite pleasant”. All 18 sets of context and sound evaluations were presented in a different random order for each subject.



(a) (b)

Figure 2 – The screenshot of the testing program: (a) comparison question; (b) evaluation questions.

Part 3 is basically same as Part 2, except that text is used to describe the contexts instead of providing pictures. For example, instead of seeing a picture in the “car horn” context, participants saw a sentence of words “you are sounding the horn of your car” when answering the comparison and evaluation questions in this context. Therefore, participants did each comparison and sound evaluation twice: one was with pictorial cues of contexts, the other with textual cues.

In Part 4, participants heard all sounds again and were asked how they like them. Four options were provided, “I really dislike it”, “I dislike it”, “I like it” and “I really like it”. They clicked on a button to input their answer. All sounds were played in a different random order for each subject and without any pictorial or textual context cues. As noted above, Part 2 and Part 3 were switched for half of the participants, thus we have 2 main groups and 4 sub-groups of participants. In Group 1, participants saw visual cues of contexts first (sub-group “1:Pic_First”), then textual cues (sub-group “1:Text_Second”). Whereas in Group 2, participants saw textual cues of contexts first (sub-group “2:Text_First”), and then visual cues (sub-group “2:Pic_Second”).

2.2 Sound Stimuli

In Table 1 is a list of the sounds used in our test. Here, we focus on the results from the 4 of the 6 contexts that are directly related to automobiles (Contexts 1, 2, 5 and 6).

Table 1 – A list of the sounds used in the test (only car-related contexts are presented).

Context #	Context	Sound #	Sound Description
1	Car door closing	1_1	“traditional”
		1_2	“between”: adding an ending beep
		1_3	“very different”: replace with a musical tone
2	Turn signal	2_1	“traditional”
		2_2	“between”: traditional sound high-pass filtered
		2_3	“very different”: replace with piano tones
5	Car horn	5_1	“traditional”
		5_2	“between”: use different instrument tones
		5_3	“very different”: use different instrument tones and rhythms
6	Windshield wiper	6_1	“traditional”
		6_2	“between”: enveloped rand noise
		6_3	“very different”: replace with musical instrument tones

Within each context, 3 sounds were created: a “traditional” sound, a “very different” sound, and a sound “between” them. Traditional sounds are recordings from automotive companies. Other sounds are created by modifying the traditional sounds by using signal processing techniques, including changing the frequency or damping of components obtained from a Prony analysis of the signal, or by using musical tones and simulating the rhythm of the original signal, etc. These musical tones are suggested by the music or film preferences of millennials (11, 12). For example, Sound 1_1 is a traditional car door closing sound (from a mass-produced sedan). Sound 1_2 is created by adding an ending beep (swept sine waves from 600 to 50 Hz) to Sound 1_1. Sound 1_3 is created by replacing the frequency components with a musical tone (E1 = 41.2 Hz) after performing a Prony analysis on Sound 1_1. Similarly, Sound 2_1 is a traditional car turn signal, whereas Sound 2_3 comprises two piano tones from Adele's "*Set Fire to the Rain*" to imitate the "tick-tock" rhythm of the traditional turn signal. Sound 2_2 is a high-pass filtered version of Sound 2_1. Pilot tests showed that the "between" sounds (e.g. 1_2, 2_2, etc.) were considered to be close to the traditional sounds (e.g. 1_1, 2_1, etc.), while the "very different" sounds (e.g. 1_3, 2_3, etc.) were considered to be far away from traditional ones. All sounds within a context were normalized to have, approximately, the same level.

2.3 Procedures

Institutional Review Board approval was gained before conducting the test. Advertisements were posted on public boards in Purdue buildings and websites. Forty subjects participated in the test: 22 females and 18 males ranging in ages from 18 to 71. The median age was 23 (mean = 27.4, *SD* = 12.1). All were working or studying at Purdue. Subjects' awareness of sound quality and noise control ranged from nothing to moderate, and none had taken acoustics or noise control courses. Six subjects had worked in noisy industries (airport, engine testing or concerts), or regularly used firearms; 5 subjects had previously been involved in sound quality tests or vibration/noise control studies; 11 subjects had studied music and/or had been involved in musical events or activities.

The test was conducted in an Acoustic Systems double walled sound booth in the Ray W. Herrick Laboratories. The playback system consisted of a LynxOne sound card, Tucker-Davis HB7 amplifier, and Etymotic Research ER-2 tube earphones. Prior to subject arrival, the left and right channels were calibrated using 85 dB, 1 kHz calibration tones with the same calibration factor as the signals used in the test. The maximum A-weighted Sound Pressure Level of each signal for each channel was recorded to check the calibration of the signals and to ensure that the sounds were presented to the subjects at a safe listening level.

The subject first read and signed a consent form and filled out a questionnaire on his/her background. Then the subject was given a hearing screening, to ensure that the subject's hearing thresholds were 20 dB or lower in all octave bands from 125 Hz to 8 kHz. The subject was then given the test instructions and a set of earphones, and instructed on how to insert the earphones. The test then started. After completing the test, the subject was given a second hearing screening, and compensated $10 for participating in the test. The whole process normally took one hour.

3. PRELIMINARY RESULTS

In this section, preliminary results from the paired comparison and sounds evaluation (appropriateness, pleasantness and overall liking) parts of the test are presented. The semantic analysis of the descriptions of the sounds and the correlations between sound preferences and sound quality metrics or information from participants' background information will be provided in future publications.

3.1 Paired Comparisons

Within each context, participants performed three paired comparisons in order to select the sound that betters matches the context. The Bradley-Terry Logit model (BTL) was used to determine the relative strength of preference for the paired comparisons (13). This model states that the probability that option "i" is chosen over option "j" ($P_{(i>j)}$) can be indicated by Eq. (1), where p_i is a positive real-valued score assigned to option "i". p_i may represent the strength of preference of the option "i".

$$P_{(i>j)} = \frac{p_i}{p_i + p_j} = \frac{e^{\beta_i}}{e^{\beta_i} + e^{\beta_j}} = \frac{1}{1 + e^{(\beta_j - \beta_i)}} \tag{1}$$

If the probabilities can be estimated, then the strength of each item can be estimated by using Eq. (1). Hunter's MM algorithm (14) was used to fit the Bradley-Terry Logit model and calculate the BTL values (β_i, β_j ...). The estimated BTL values of the sounds used in the 4 contexts when combining the comparisons across all 4 sub-groups of participants (1:Pic_First, 1:Text_Second, 2:Text_First and 2:Pic_Second) are shown in Table 2. The additional constraint used to determine the BTL values, is that the traditional sound BTL value, β_1, in each context is set to 0 (p_1=1); all other BTL values as either greater than or less than 0. A sound with a larger BTL value is more likely to be chosen in paired comparisons within the given context. As shown in Table 2, in Contexts 1, 2 and 5, participants were less likely to choose those modified and new sounds, whereas in Context 6 they were more likely to choose them. In all of the four contexts, participants showed higher preference for Sound 2 ("between") than for Sound 3 ("very different"), and in Context 2 this preference is much more noticeable.

Table 2 – BTL values of the sounds in 4 contexts, estimated from the subjects' selections of sounds based on which they would prefer to hear in a context.

Context Number	Context	Sound 1 "Traditional"	Sound 2 "Between"	Sound 3 "Very different"
1	Car door closing	0.000	-1.027	-1.173
2	Turn signal	0.000	-0.243	-1.399
5	Car horn	0.000	-0.898	-1.564
6	Windshield wipers	0.000	1.367	1.255

The BTL values of the sounds for the four sub-groups in Context 1 (car door closing) are shown in Fig. 3(a). It is interesting to see that participants in sub-group "2:Text_First" preferred Sound 1_3 slightly more than Sound 1_2, while participants in other sub-groups showed the opposite preferences. The results for Context 6 (windshield wipers) are shown in Fig. 3(b). Here we can observe that Group 2 (sub-groups of "2:Text_First" and "2:Pic_Second") seemed to prefer Sound 6_3 to Sound 6_2, whereas Group 1 (sub-groups of "1:Pic_First" and "1:Text_Second") did not. Note, in these two contexts for both Group 1 and Group 2, the BTL values are always higher when pictures are shown (in the graph, for the same colors triangles are always higher than circles). These results indicate that pictorial or textual information could impact how people make choices between sounds during a paired comparison test.

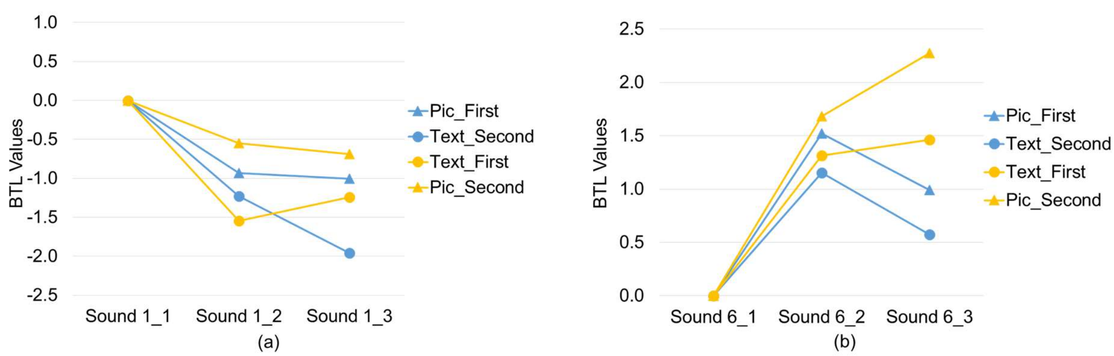


Figure 3 – BTL values of the sounds in four sub-groups. Twenty subjects in each group: Group 1 - blue, Group 2 - yellow. (a) Context 1: car door closing; (b) Context 6: windshield wipers.

3.2 Sound Evaluations

Preliminary results of the sound evaluations (appropriateness, pleasantness and liking evaluations) are presented in this subsection. In Fig. 4 are shown the average of the appropriateness ratings (Appropriateness) of each sound for the 4 sub-groups for each of the 4 contexts. The error bars show the standard error of the average estimates. Here shorter names for the sub-groups are used (Group 1: P1 is "1:Pic_First"; T2 is "1:Text_Second"; Group 2: T1 is "2:Text_First"; P2 is "2:Pic_Second"). The appropriateness rating value ranges from -2 (quite inappropriate) to +2 (quite appropriate), and 0 means neutral.

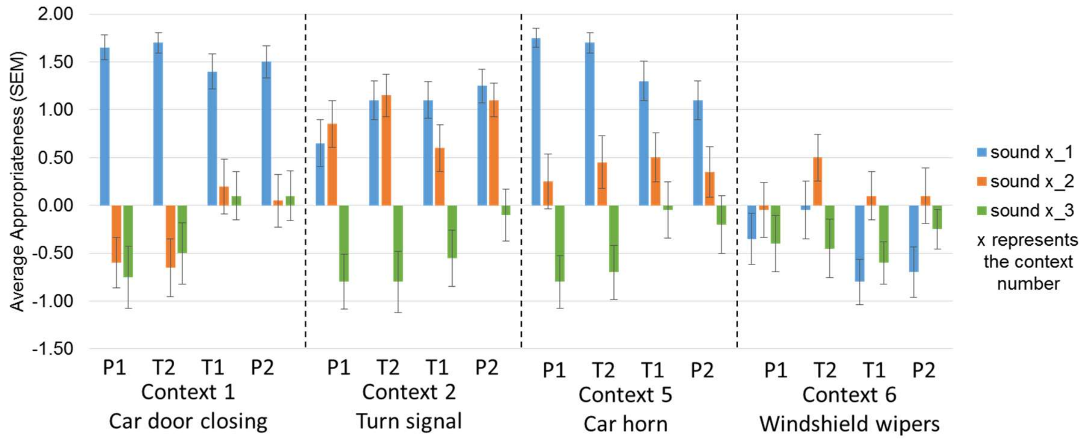


Figure 4 – The average of the appropriateness ratings of each sound. Bars indicate ± the standard error.

Generally, participants considered "traditional" sounds to be more appropriate in Contexts 1, 2 and 5, and the "very different" sounds to be inappropriate in Contexts 2, 5 and 6. The Appropriateness values in Context 2 (turn signal) and Context 5 (car horn) seem to be basically consistent across all 4 sub-groups. Note that in Context 1 (car door closing), participants from Group 1 (P1 and T2) rated Sounds 1_2 and 1_3 as more inappropriate than participants from Group 2 (T1 and P2) did. For Sound 1_2's Appropriateness, a two-sample t-test ($\alpha = 0.05$, same value used henceforth) between Group 1 and Group 2 results indicates this difference is significant ($t(77) = -2.68$, $p = 0.004$). For Sound 1_3's appropriateness, the t-test between Group 1 and Group 2 also indicates a significant difference ($t(74) = -2.52$, $p = 0.007$). In Context 6 (windshield wipers), sub-group T2 gave higher appropriateness ratings to Sound 6_2 than P1, although the t-test result shows that this difference is not significant ($t(37) = -1.46$, $p = 0.076$).

In Fig. 5 are shown the average of the pleasantness ratings (Pleasantness) along with the standard error. Again results for all 4 sub-groups (P1, T2, T1, P2) within 4 contexts are shown. The pleasantness ratings range from -2 (quite unpleasant) to +2 (quite pleasant), and 0 means neutral. In general, people gave positive ratings of pleasantness to the sounds in Context 1 and 2, but negative ratings in Context 5 and 6. We observe that in Context 1, participants from Group 2 (T1 and P2) rated the "very different" sound (i.e. Sound 1_3) as more pleasant than Group 1 (P1 and T2) did ($t(76) = -1.99$, $p = 0.025$). Similar results can be seen in Context 5 ($t(76) = -2.07$, $p = 0.021$).

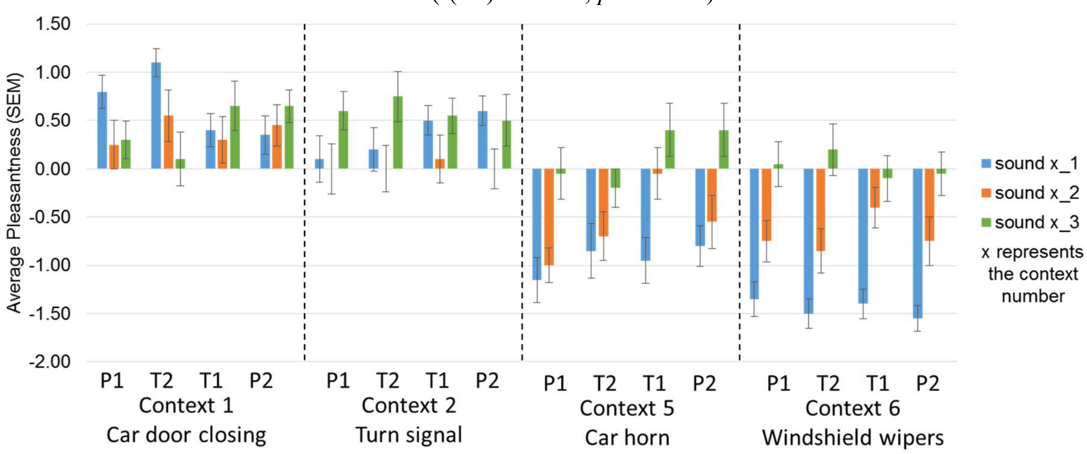


Figure 5 – The average of the pleasantness ratings of each sound. Bars indicate ± the standard error.

In Fig. 6 the average overall liking ratings are shown along with standard error bars for all the sounds presented within 4 contexts. The overall liking evaluations range from -1.5 (I really dislike it) to +1.5 (I really like it). Since all participants rated the overall liking without any pictorial or textual cues of context, results here are not shown separately by sub-groups. The overall liking results are consistent with the pleasantness results above. Sound 2_3 (musical turn indicator) received the highest Overall Liking value, although its BTL value (preference in the given context) and Appropriateness value are very low (see Table 2 and Fig. 4).

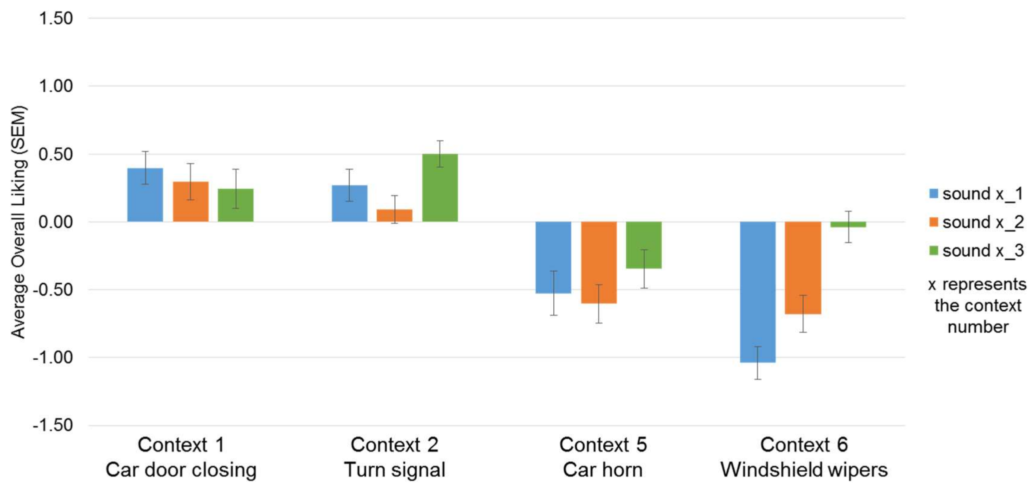


Figure 6 – Average of overall liking ratings (Liking values) with standard error bars (± standard deviation of the estimated mean) for the 12 sounds.

3.3 Correlations among Sound Evaluations and Preferences

The Appropriateness, Pleasantness, Liking and BTL (preference within the context) values, are plotted against each other in Figs. 7 and 8. Results are shown for the 4 subgroups separately.

As illustrated in Fig. 7, the Pleasantness Liking values are positively correlated in all 4 sub-groups: 1:Pic_First (R^2 = 0.955), 1:Text_Second (R^2 = 0.939), 2:Text_First (R^2 = 0.667), 2:Pic_Second (R^2 = 0.762). This result illustrates the strong connection of participants' evaluation in pleasantness and overall liking of sounds, no matter whether pictorial, textual or no cues of contexts are provided during the sound playback. We can also see that the correlation is slightly lower for Group 2 (Fig. 7 (c) and (d)) than for Group 1 (Fig. 7 (a) and (b)). Correlations between Appropriateness and Pleasantness values, and correlations between Appropriateness and Liking values are insignificant. This reveals that appropriateness may not be necessary related to the pleasantness or liking of a sound.

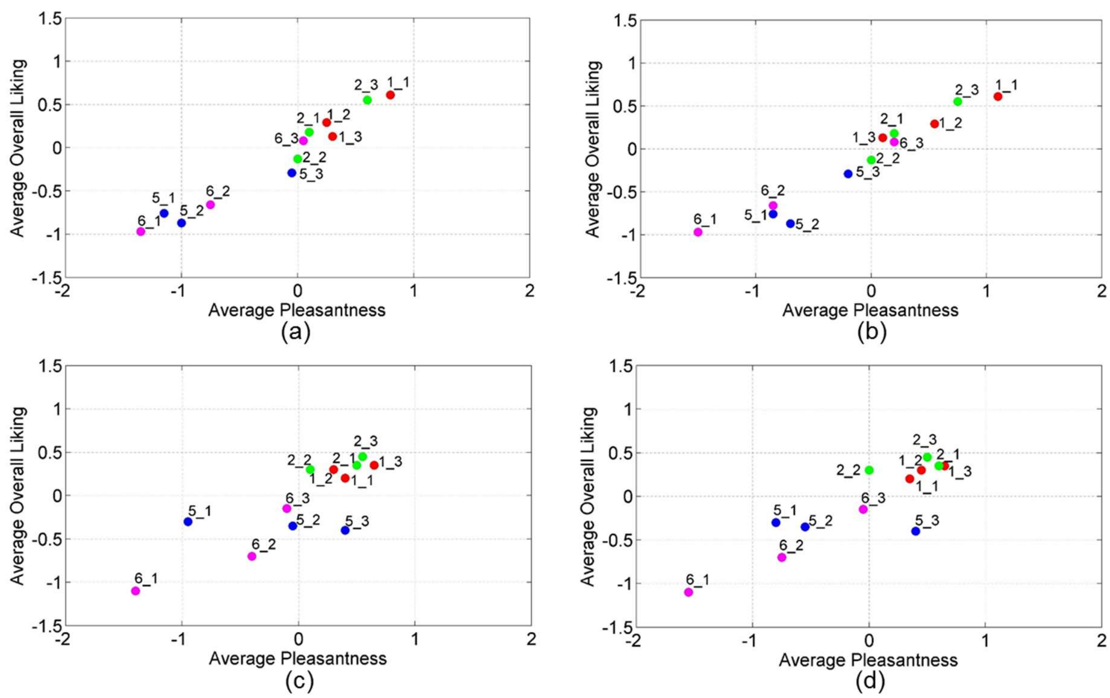


Figure 7 – Plots of the correlation between Pleasantness and Liking values of each sound. (a) sub-group "1: Pic_First"; (b) sub-group "1:Text_Second"; (c) sub-group "2:Text_First"; (d) sub-group "2: Pic_Second". Red, green, blue and pink represent sounds in Context 1 (car door closing), 2 (turn signal), 5 (car horn) and 6 (windshield wipers), respectively.

In Fig. 8, the correlations between Appropriateness values and the BTL values from the comparison test are also significant in all 4 sub-groups: 1: Pic_First (R^2 = 0.423), 1:Text_Second (R^2 = 0.610), 2:Text_First (R^2 = 0.510), 2:Pic_Second (R^2 = 0.410). Note that here the BTL values of all "traditional" sounds (*i.e.* Sound x_1, x is the context number) were set to their appropriateness values, and the BTL values of other sounds were adjusted accordingly. Correlations between Pleasantness and BTL values, and correlations between Liking and BTL values are not significant. It is concluded that participants were more likely to choose the sounds that they thought to be appropriate in the given contexts even if the sounds were not pleasant to them or they disliked them. It is also interesting to observe that this correlation between appropriateness and BTL value is slightly stronger for the sub-groups seeing textual cues of context than for the sub-groups seeing pictorial cues (compare the Fig. 8 (b) vs. (a), (c) vs. (d)).

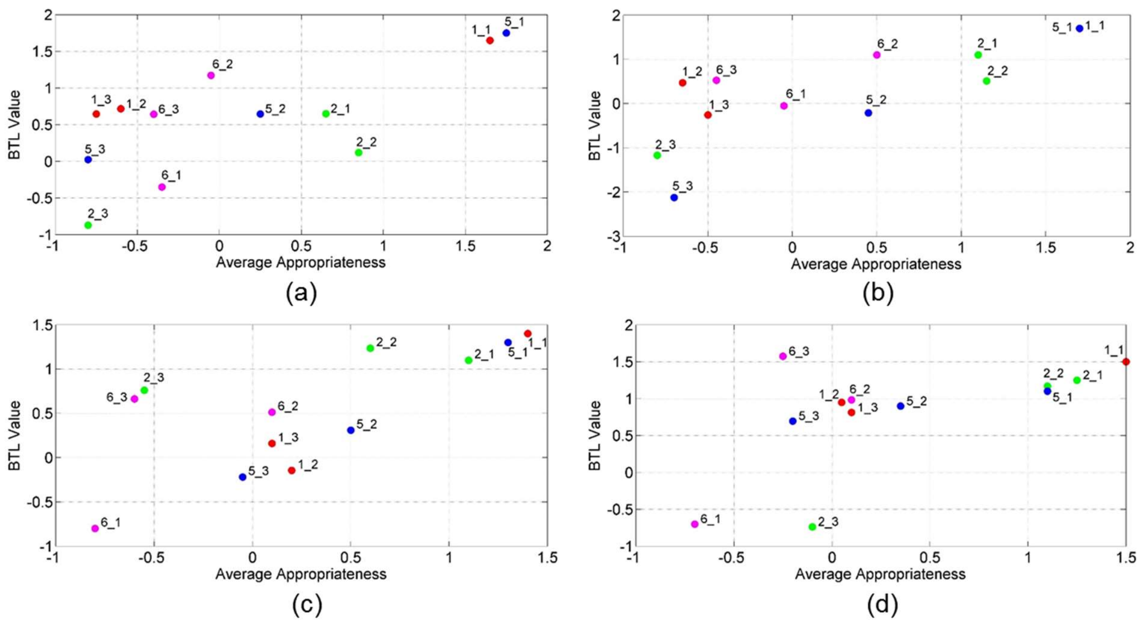


Figure 8 – Correlation between Appropriateness and BTL values of each sound. (a) sub-group "Pic_First"; (b) sub-group "Text_Second"; (c) sub-group "Text_First"; (d) sub-group "Pic_Second". Red, green, blue and pink represent sounds in Context 1 (car door closing), 2 (turn signal), 5 (car horn) and 6 (windshield wipers), respectively.

4. DISCUSSIONS AND CONCLUSIONS

Preliminary results of this test show that in most cases, participants tended to choose more traditional sounds in the given contexts. Even when choosing the "between" sounds and the "very different" sounds, they still preferred the sounds closer to the traditional ones. The only exception is the traditional Sound 6_1 in Context 6 (windshield wipers). The scratchy part of this sound made participants feel uncomfortable, and probably made them think that the mechanical parts of the wipers may not work very well. Some participants even commented this sound as a signal of a pair of "broken wipers", though the picture of a pair of well-working wipers was shown in the test. In contrast, the modified sounds (Sound 6_2 and Sound 6_3) did not have the high frequencies present due to the "scratchy" component of the recording and participants felt that these were gentler and smoother (results from the descriptions provided by participants), which could explain why participants choose them instead of the traditional sound.

Sound evaluations provide more insight into how participants perceive and judge these sounds. Generally, participants considered "traditional" sounds to be more appropriate in contexts 1, 2 and 5, and the "very different" sounds to be inappropriate in contexts 2, 5 and 6. This result is consistent with their choices in the paired comparisons. The average Appropriateness and the BTL values of each sound are positively correlated in all 4 sub-groups (see Fig. 8). Additionally, we didn't find significant correlation between Appropriateness and Pleasantness values, correlation between Pleasantness and BTL (preference within the context) values, nor correlation between Liking and BTL values. This result indicates that participants were more likely to choose the sounds that they thought better matched the given contexts, even though these sounds were not pleasant to them or they disliked them. For example in Context 5 (car horn), participants might think that this sound doesn't have to be too pleasant because the horn sound is mainly used to get others' attention. Another example is the Sound 2_3 which consists of two piano tones based on a popular song sound clip. This sound had the highest Liking value, however, its Appropriateness and BTL value are quite low (see Table 2 and Fig. 4). From this discussion, we may conclude that the priority in the design of car sounds is to convey the correct signal/function/meaning of the context to listeners. If the sound fails to convey such information or the sound conveys incorrect information (e.g. Sound 6_1 with the "broken wipers"), people will likely not accept them in certain contexts.

It is clear that visual contextual information can strongly affect participants' sound perception and evaluation. For example, in Fig. 3(b) it can be seen that Group 2 (textual cues of context first, pictorial second) seemed to prefer Sound 6_3 to Sound 6_2, while Group 1 (pictorial cues first, textual second) preferred Sound 6_2 to Sound 6_3. Even Group 1 when evaluating the appropriateness of sounds in Context 6 (windshield wipers), found Sound 6_2 more appropriate when they heard it the second time with the textual cue than when they heard it the first time with the picture cue, though the t-test result doesn't show this to be a significant difference using the two-sample t-test of $\alpha = 0.05$ (t (37) = -1.46, p = 0.076). Another example is that in Context 5, where participants from Group 2 (T1 and P2) thought the "very different" sound (i.e. sound 5_3) to be more pleasant than Group 1 (P1 and T2) did (t (76) = -2.07, p = 0.021). These results indicate that different forms of visual presentation of contexts (pictorial or textual) and the order of showing them can both impact how participants evaluate product sounds in certain contexts.

In summary, from the preliminary results of this test we conclude that millennials are more likely to accept the traditional sounds in the given car contexts. Modified or innovative sounds might be interesting or even more pleasant to them, however when they found these sounds to be inappropriate in the contexts, they did not prefer them. We also found that the pictorial and textual cues of context and their presentation order could impact how people perceive sounds in certain contexts. These results may shed light on how to design future car sounds considering the end-users' sound preferences, and also, of course, on the need to be careful in how context cues are presented in subjective tests.

A limitation of this study is the lack of consideration of how millennials' might learn or adapt to new sounds. If they hear the "very different" sounds for a certain amount of time, we don't know if they would still mostly hold negative opinions on the acceptability of those sounds in particular contexts. Future steps in this research include: a more in-depth analysis of the test results (consideration of all six contexts, analysis of sound descriptions and their relationship to sound attributes, etc.); exploration of learning and adaptation effects; and development of a model to predict how people would evaluate those innovative sounds in certain car contexts. The following factors will be considered in such a model: acoustic attributes of sounds (loudness, frequency balance, cleanness, etc.), visual representation of cars (pictures, videos, virtual reality simulation, and physical contact), and participants' background (age, gender, driving experience, etc.).

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