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A study of evaluating the button sounds

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A lot of attention has been directed at designing various sounds that are treated as noise, such as automobile acceleration sounds and cleaner sounds. The idea of sound being a normal part of product operation has permeated society. We focused on sound design and evaluated it with 11 kinds of button sounds. First, an impression was extracted by the semantic differential (SD) method, and the relevance of that impression was investigated by time frequency analysis. Next, we confirmed whether or not the impression changed when a sound that generated a bad impression was processed using an adaptive control into a sound that generated a good impression.

1 Introduction

A lot of attention has been directed at designing various sounds that are treated as noise, such as automobile acceleration sounds and cleaner sounds. The idea of sounds being a normal part of product operation has permeated society. We focused on sound design and evaluated it with 11 kinds of button sounds. First, an impression was extracted by the semantic differential (SD) method, and the relevance of that impression was investigated by time frequency analysis.

Visualization (also known as 'time-frequency representation of an impression') was produced from the extracted impression. Future button sound design may reflect this discovery. We also confirmed that impressions changed when a sound that generated a bad impression was processed using an adaptive control into a sound that generated a good impression.

Since hearing is known to be influenced by vision and touch we then investigated the relevance of touch on the time-frequency representation of an impression.

2 Time-Frequency Analysis

2.1 Wavelet Transform (WT)

WT is a multi-resolution analysis which is useful for matching with auditory impressions. WT is obtained by calculating the inner product of the signal $f(t)$ and $AW\psi(t)$ in the following formula [5]:

$$WT_f(b, a) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} \psi^*\left(\frac{t-b}{a}\right) f(t) dt \quad (1)$$

Variable a is a scale parameter used in performing similarity transformation. Variable b is a shift parameter which is used in the translation of $\psi(t)$. WT is initially expressed in the $t-s$ time-scale plane, but it can be regarded as an approximation of the $t-f$ distribution by using a time- and frequency-localized AW. We selected a Morlet wavelet in a preliminary experiment.

2.2 Experimental condition

Eleven types of button for use in 6 models of car audio unit were evaluated. Data recording was performed in an anechoic chamber. Each button was pushed 3 times, and the sound was recorded with a microphone in a position about 30 cm away from the main unit. The sound made by pushing the button (push sound) and the sound made by detaching the button (back sound) are depicted.

2.3 Sound Quality Metrics

Sound quality metrics (loudness, sharpness, etc.) attempts to represent the psychoacoustical features of hearing numerically [7]. Loudness is standardized by ISO 532B for stationary sound. A sound quality evaluation was performed using loudness.

The relation between the jury test "like-dislike" score (explained in the following section) and loudness is shown in Fig. 1. It shows that as a sound becomes louder, the impression left on those hearing it becomes worse. There was a similar tendency in hearing impressions when analysis of "comfortable - jarring" sound and "exclusive - cheap" sound was performed. However, loudness is used to evaluate stationary sound, and cannot be adequately used for evaluation of unsteady sounds like button sounds. As a result, we decided to compare time-frequency structure and the jury test score.

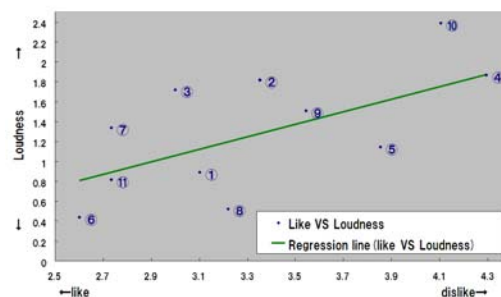


Figure 1: The relation between the score of the "like-dislike" of the jury test and loudness

2.4 Analysis conditions and results

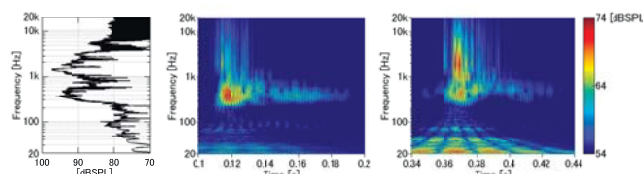
WT results for every main unit are shown in Figs. 2 -7. Each figure includes the DFT magnitude and the WT of push sounds and back sounds. Morlet wavelets were used as the AW.

Low frequency button sounds tended to receive a high score on a jury test "like-dislike" subjective evaluation. As sound frequency increased, evaluation scores decreased. Evaluation scores were also affected by the duration of the energy burst.

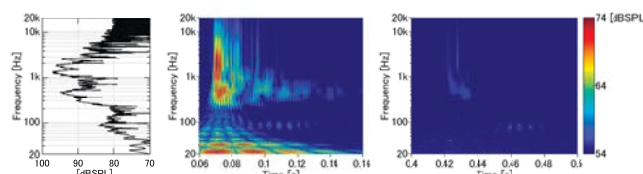
3 Jury test

3.1 Quantification of Psychoacoustics

"Loudness," "pitch," and "sound quality and tone" were used for psychoacoustic quantification [7]. Loudness was equivalent to a physical quantity, called the sound pres-

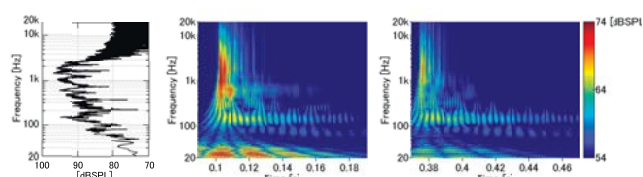


(a) Button(1)

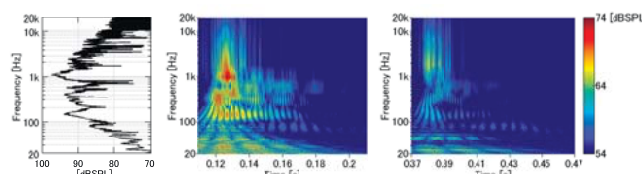


(b) Button(2)

Figure 2: Magnitude response of the main unit 1; (left) DFT of Push and Back sound, (center) WT of Push sound, (right) WT of back sound.

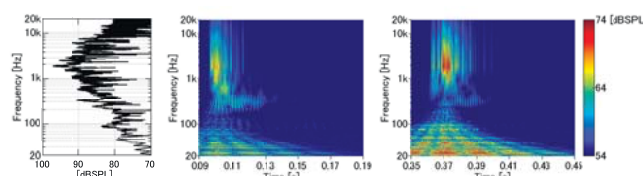


(c) Button(3)



(d) Button(4)

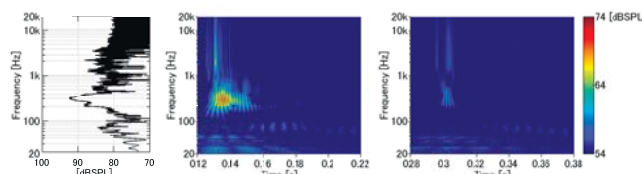
Figure 3: Magnitude response of the main unit 2; (left) DFT of Push and Back sound, (center) WT of Push sound, (right) WT of back sound.



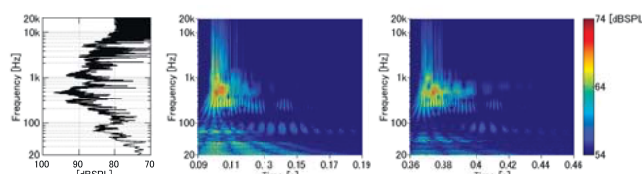
(e) Button(5)

Figure 4: Magnitude response of the main unit 3; (left) DFT of Push and Back sound, (center) WT of Push sound, (right) WT of back sound.

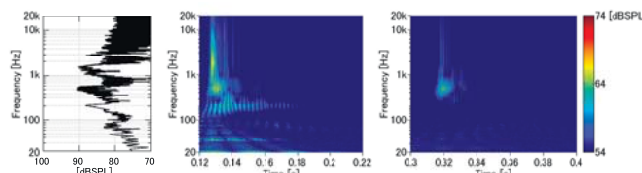
sure level. Sound frequency was related to pitch, and the time-varying structure, spectrum, etc., was related to sound quality and tone. These are called the sensational dimensions. However, when they are set up to examine sound quality, various dimensions, such as "bright," and "hard," can be found. Quantifying the number of dimensions involved in producing the magnitude and the pitch of sound should be simple. The SD method enabled us to quantify the sensational dimensions in the experiment. The SD method has many adjective scales expressing sound quality and tone, and it measures sound using these scales. Factor analysis was used to evaluate the common factors from these re-



(f) Button(6)

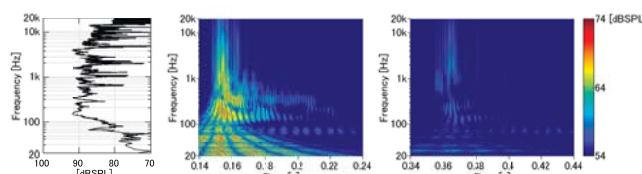


(g) Button(7)



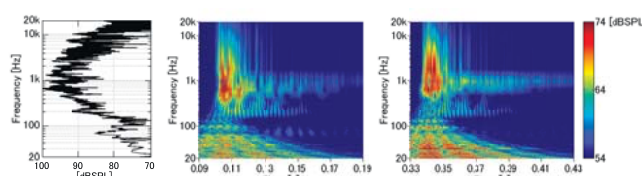
(h) Button(8)

Figure 5: Magnitude response of the main unit 4; (left) DFT of Push and Back sound, (center) WT of Push sound, (right) WT of back sound.

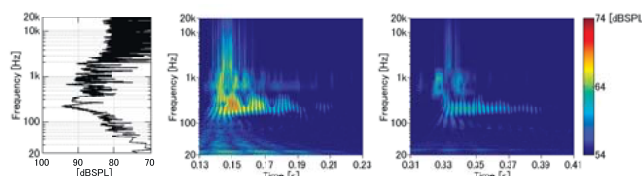


(i) Button(9)

Figure 6: Magnitude response of the main unit 5; (left) DFT of Push and Back sound, (center) WT of Push sound, (right) WT of back sound.



(j) Button(10)



(k) Button(11)

Figure 7: Magnitude response of the main unit 6; (left) DFT of Push and Back sound, (center) WT of Push sound, (right) WT of back sound.

sults, and determine and quantify dimensionality.

3.2 Auditory experiment and result

A jury test was conducted using the SD method with 67 healthy people forming the jury. Sounds were repro-

duced through headphones. The evaluation paper used in the jury test is shown in Fig. 8. The age and gender distribution of subjects in the jury is shown in Fig. 9. The experimental results are shown in Fig. 10.

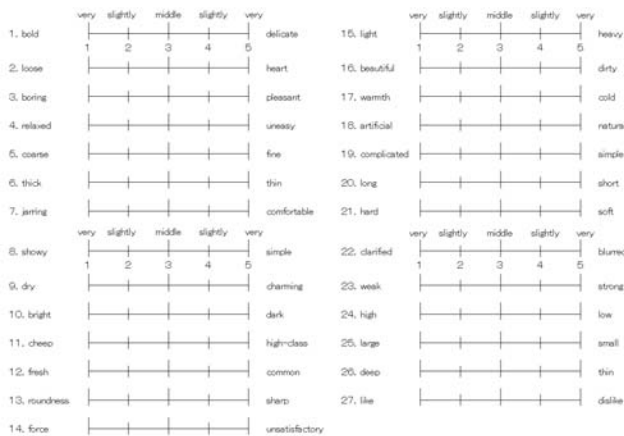


Figure 8: Evaluation paper

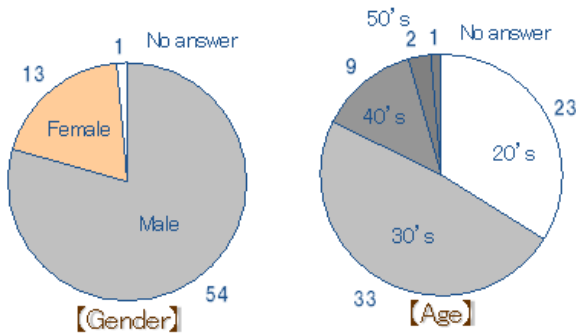


Figure 9: Subjects

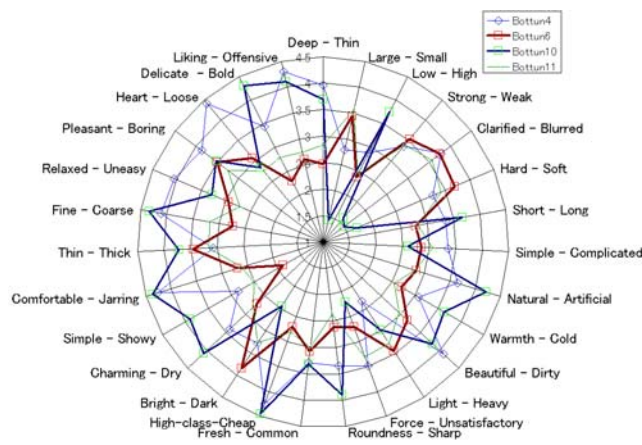


Figure 10: Subjective evaluation

First, each adjective was matched with a button.
 button (6) – "dark" – "deep" – "simple" – "soft" – "heavy" – "liking" – "high-class" – "low" – "charming"
 button (11) – "round" – "warm" – "fresh" – "natural"
 button (7) – "beautiful" – "pleasant" – "relaxed" – "heart"
 button (3) – "simple"

button (1) – "common" – "simple"
 button (8) – "small" – "weak" – "fine" – "thin" – "unsatisfactory" – "delicate" – "short"
 button (2) – Nothing
 button (9) – Nothing
 button (5) – "light" – "thin" – "high" – "cold"
 button (10) – "large" – "strong" – "clarified" – "force" – "bold" – "showy" – "hard" – "long" – "artificial" – "dry" – "coarse" – "thick" – "bright" – "sharp" – "cheap" – "jarring"
 button (4) – "loose" – "uneasy" – "offensive" – "complicated" – "dirty" – "boring" – "blurred"

WT showed that the back sound of button (4) produced a sweep sound at 100-600 Hz. The adjectives "loose", "uneasy," and "tendency" were associated with this sweep sound distribution. Continuous low-pitched sounds were associated with button (3) but these sounds did not influence the auditory impression. A continual high-pitched sound was associated with button (10) and this sound was described using the adjectives "long," and "cheap." However, sound quality matching was insufficient because the correlation was between adjectives.

3.3 Factor analysis

Factor analysis and WT matching analysis of these experimental results were conducted. The relationship between each button sound and factor was investigated using ten pairs of adjectives which were significantly different from a set of 27 overall pairs of adjectives. Factor loadings and factor scores are shown in Table 1 and Fig. 11, respectively. The principal divisor method and the varimax rotation method were used for factor extraction.

A metallic factor, an esthetic factor, and a force factor were extracted sequentially from the first factor. These are "hard," "comfortable," and "powerful" sounds, so their jury test scores were high. Moreover, the accumulation contribution was fully satisfied.

"Favorite" button sounds had low metallic factor and force factor scores, and had a high esthetic factor score, as shown in Fig. 11. When a button sound was classified as "offensive" the metallic factor and force factor scores were high but the esthetic factor score was low. These results correspond with the results from WT experiments shown in Figs. 2 – 7.

Table 1: Factor loadings

	Metallicity	Esthetic	Force	Similarity
Hard - Soft	0.91	-0.20	0.33	0.97
Clarified - Blurred	0.90	-0.10	0.41	0.98
Low - High	0.86	-0.39	-0.01	0.90
Simple - Showy	-0.63	0.52	-0.46	0.88
Comfortable - Jarring	-0.22	0.95	-0.14	0.96
High-Class - Cheap	-0.36	0.91	0.12	0.96
Fine - Coarse	-0.09	0.88	-0.42	0.95
Force - Unsatisfactory	0.15	-0.02	0.95	0.92
Strong - Weak	0.65	-0.20	0.74	1.00
Large - Small	0.50	-0.45	0.71	0.95
Factor contribution	36.41	32.02	26.48	94.90

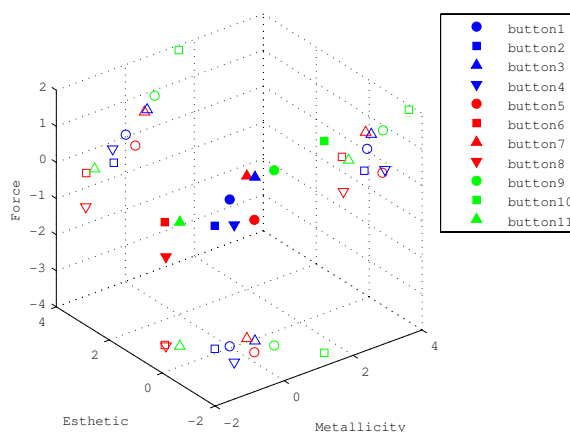


Figure 11: Factor score

4 Touch evaluation

This experiment (like the auditory evaluation) was conducted by the SD method, and was designed to evaluate the influence of the touch of a finger on sound impression. So that the buttons in the system could be pushed and the effects evaluated, the influence of vision was also considered. The evaluation paper used in the touch experiment is shown in Fig. 12. The subjects who took part in the auditory evaluation also took part in the touch evaluation. Results are shown in Fig. 13.

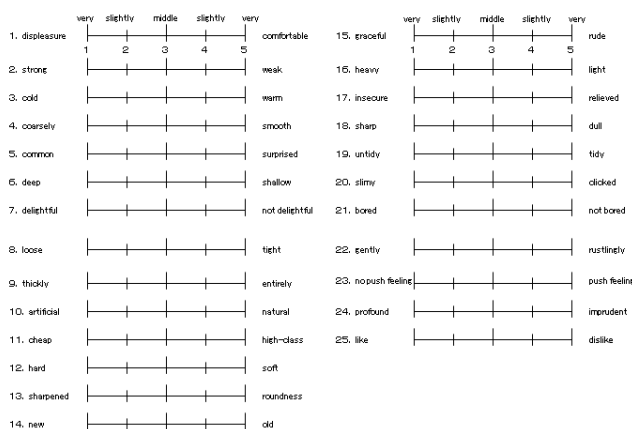


Figure 12: Evaluation paper

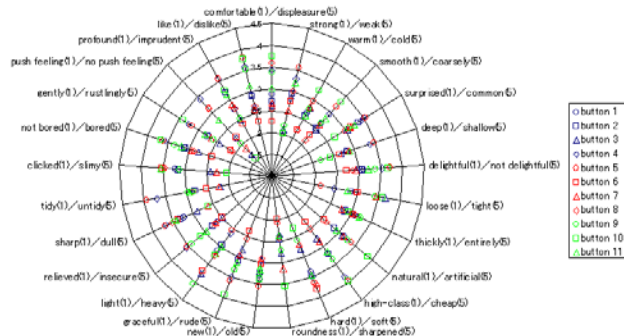


Figure 13: Subjective evaluation

Each adjective was matched with the button that was

mostly closely described by that adjective and with the button that was least closely described by that adjective. Results are shown sequentially starting with the adjectives that had the largest differences in the touch evaluation of buttons.

Button 6 – "like" – "comfortable" – "warm" – "delightful" – "natural" – "high-class" – "round" – "graceful" – "not bored" – "profound" – "soft"

Button 11 – "slimy"

Button 7 – "entirely"

Button 3 – "tidy" – "relieved" – "tight"

Button 1 – Nothing

Button 8 – "smooth" – "new" – "gentle"

Button 2 – Nothing

Button 9 – "deep" – "thick"

Button 5 – "loose" – "light" – "offensive" – "weak" – "common" – "shallow" – "not delightful" – "cheap" – "old" – "sharp" – "untidy" – "imprudent"

Button 10 – "strong" – "surprised" – "hard" – "sharp" – "clicked" – "push feeling" – "displeasure" – "cold" – "coarse" – "artificial" – "sharp" – "rude" – "bored" – "rustling"

Button 4 – "insecure" – "no push feeling"

4.1 Factor analysis

In addition to performing an auditory evaluation, a factor analysis of the touch evaluation was conducted. Factor loadings and factor score are shown in Table 2 and Fig. 14, respectively. The principal divisor method and the varimax rotation method were used for factor extraction.

Results were extracted as either a comfort factor or a strength factor sequentially from the first factor. The touch factors extracted were a "comfortable" feel and a "strong" feel, so that the jury test score was high and the accumulation contribution was fully satisfied. The strength factor did not contribute to a button being a "favorite". When a button was a "favorite", the comfort factor score was high, as shown in Fig. 14. After performing matching with WT, a high comfort factor score was found when the button power was concentrated in a low frequency WT region.

Visualization of the auditory and touch impressions of buttons is shown in Fig. 15. The score of "like" was associated with buttons that were placed high in the system when looked at sequentially from the upper left. Frequency and duration of sound were both related to auditory and touch impressions.

5 Sound quality control

Adaptation signal processing enabled control of sound quality. Button (10) (which generated the worst impression) was made into the reference signal, $x(n)$, and button (6) (which generated the best impression) was made into the desired signal, $d(n)$, on an LMS algorithm. The

Table 2: Factor loadings

	Pleasure	Strong	Similarity
Pleasure - Displeasure	0.99	0.03	0.98
Graceful - Rude	0.99	-0.05	0.98
High-Class - Cheap	0.98	0.15	0.98
Liking - Offensive	0.97	0.14	0.96
Strong - Weak	0.02	0.99	0.98
Loose - Tight	-0.18	-0.98	0.99
Push Feeling - No Push Feeling	0.08	0.90	0.81
Hard - Soft	-0.40	0.88	0.93
Tidy - Untidy	0.65	0.71	0.92
Light - Heavy	-0.38	-0.69	0.62
Factor contribution	0.46	0.45	0.92

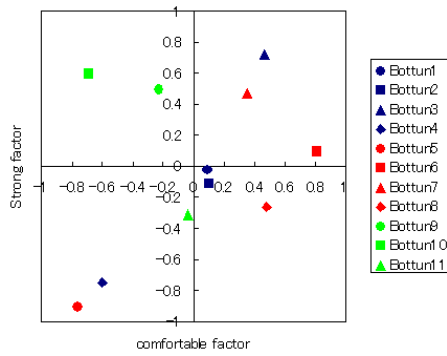


Figure 14: Factor score

adaptation filter had 512 taps, and a filter output, $y(n)$, was observed. The WT results of $y(n)$ and $d(n)$ after convergence are shown in Fig. 16. These results show that the signal that generated the worst impression signal changed to a distribution close to the desired signal when LMS algorithms were applied. The filter output $y(n)$ generated an auditory impression similar to the button sound classified as "like."

6 Conclusions

We focused on sound design and evaluated it with 11 kinds of button sounds. First, an impression was extracted using the SD method, and the relevance of that impression was investigated by time frequency analysis. After matching WT characteristics and auditory impressions the results showed that a low frequency button sound made a favorable impression, and a high frequency button sound made a poor impression. The auditory impression of both button sounds was classified into esthetic, metallic, and force factors on the basis of these results. We also confirmed that impressions changed when sounds with a bad impression were processed using an adaptive control into sounds with a good impression.

These results should influence button sound design in the future. In addition, part of this study was made possible by SCAT Foundation.

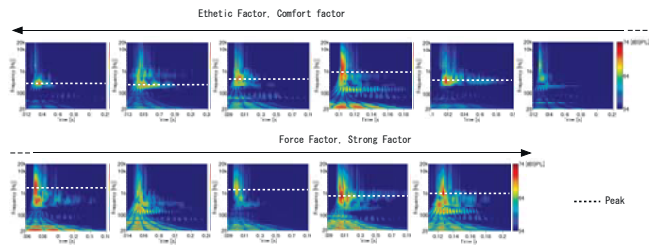


Figure 15: Visualization of the impression of hearing and touch; the button of a good impression of "like" is shown sequentially from the upper left.

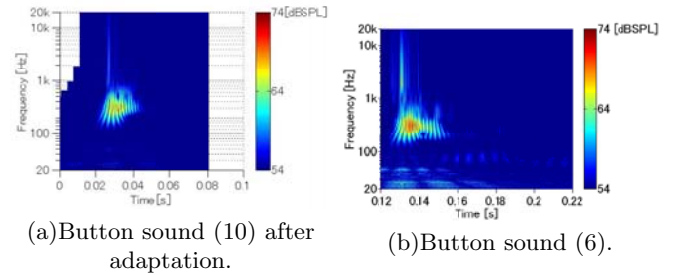


Figure 16: Comparison between WTs of the button sound after signal processing (10) and the button sound (6)

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