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CULTURAL DIFFERENCES IN RESPONSES TO REFRIGERATOR NOISE

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ABSTRACT
Korean-born and US-born subjects were asked to compare refrigerator sounds in terms of annoyance. The sounds were also evaluated with objective measures (metrics) and linear combinations of metrics were used to predict annoyance. Korean-born subjects were found to be more sensitive than the US-born subjects, though the orderings of the signals in terms of annoyance by both groups were similar. Predictions from models containing Stationary Loudness and Zwicker Sharpness metrics were strongly correlated with subjective responses. There appeared to be slight differences in the individual contributions of Sharpness and Loudness to annoyance between the two groups, but further research is needed to determine if these differences are significant.

1 - INTRODUCTION

Manufacturers of home appliances are increasingly concerned with the sounds of their products. Most noise ratings of appliances are currently tailored to A-weighted sound pressure level (dBA), but there is a growing awareness that lowering dBA does not necessarily guarantee customer satisfaction [1]. A-weighted sound pressure level is not an accurate predictor of loudness. There are many characteristics, e.g., the level, the balance of high versus low frequencies in a sound, the temporal variation in the sound, and the presence of audible tones, that contribute to a person's perception of a sound. Of concern to engineers working in the appliance industry is that use of dBA as a criterion may push noise control efforts in the wrong direction. Reduction of low frequency components could significantly change the character of the sound by unmasking more annoying higher frequency sound components.

Most appliance manufacturers sell their products in many countries and so cultural differences in perception of appliance are of interest. There is evidence that cultural differences do exist. German and Japanese subjects' perceptions of the loudness of impulses and simulated traffic noise were found to be similar [2], but differences in the perception of loudness, noisiness and annoyance between German and Japanese groups have been observed when different types of noises such as interior car noise, speech, music and artificial sounds were presented to subjects [3,4,5]. Differences have also between observed between groups of Japanese and German students evaluating the pleasantness of sounds, and the groups also exhibited different levels of confidence when identifying sounds [6].

Cross-cultural differences in meanings and attitudes towards word concepts, such as loudness and annoyance, are different amongst Chinese, Japanese, English, and German subjects [7]. American and English subjects are similar in their responses to the meanings of noise concepts, attitudes about noise, and attitudes concerning regulations dealing with noise problems, while in Japan it is conjectured that there is concern about making noise and people may be more willing, than people in the U.S. and England, to assume the cost of strict noise-emission standards for appliances [8]. In contrast to subjects from Sweden, China, Germany and the US, Japanese subjects appear not to distinguish between *noisy* and *annoying*, and while German and American subjects perceive *loud* as being negative, Japanese, Chinese

and Swedish subjects view *loud* as a neutral term [9]. Vallet and Schmeltz [10] have concluded that there are international differences in the uses of terms used to describe the loudness, noisiness and annoyance from noise, and that more research is in order to, perhaps, create a culturally-based weighting for the evaluation of noise.
A subjective test was conducted to answer the following questions.

1. Do Korean and US subjects perceive refrigerator sounds differently?
2. Which objective measures have the strongest correlation to annoyance?
3. Can linear combinations of metrics be used to predict subjects' annoyance, and do the Korean response models differ from the US response models?

2 - THE SUBJECTIVE TEST

Twelve Korean born and raised and twelve US born and raised subjects took a paired comparison test in an anechoic chamber while seated at a PC and wearing headphones. Only subjects with normal hearing took the test. A practice test was administered to familiarize each subject with the task before proceeding to the full test. The 17 signals were randomly paired by the testing software and a different order of presentation generated for each subject. Subjects heard the presentation as (Signal A, Signal B) and as (Signal B, Signal A) at different points in the test.
The headphone signal level was set by the researcher by adjusting the headphone amplifier until a comfortable listening level was achieved. Once this level was determined, all subjects were tested with the same amplifier setting. The signals were presented at a higher sound pressure level than the actual level recorded by the refrigerator manufacturer. Subsequent to the test reported here, other tests were conducted where the sounds were played back at the recorded levels.
The 17 test signals were from three different refrigerators of similar capacities, operating in different configurations. One of the signals was a transient; the others were *quasi steady state* taken at different points in the refrigerator cycle. The configurations are shown in Table 1. Signals' start and end points were tapered so as to avoid noticeable transient effects (clicks or extended ramps).
The probability of choosing one signal over another was estimated from the response data, and in the process ordering effects were reduced by averaging with the results from when the sounds were played in reverse order. The probabilities were transformed to BTL scaled values [11], a measure of the annoyance sensation and normalized to be centered on zero. The results are shown in Figure 1.
The responses to the sounds could be ordered almost identically for the two groups, but the annoyance response from the Korean-born group was much stronger. The Korean responses can be predicted quite accurately (R^2=0.98, p=0.00) from the US responses by applying a factor of 2.2. The least annoying signals: 13,17 and 9, were the ones with just the fan running and the compressor only signals (8,16 and 12) were in the midrange of annoyance.

Signal	Model	Refrigerator	Signal	Model	Refrigerator
1	A	cold start	10	B	cold start
2	A	cold start (startup transient)	11	B	warm start
3	A	cold start	12	B	compressor on, fan off
4	A	cold start	13	B	compressor off, fan on
5	A	cold start	14	C	cold start
6	A	warm start	15	C	warm start
7	A	warm start	16	C	compressor on, fan off
8	A	compressor on, fan off	17	C	compressor off, fan on
9	A	compressor off, fan on			

Table 1: Description of the 17 test signals used.

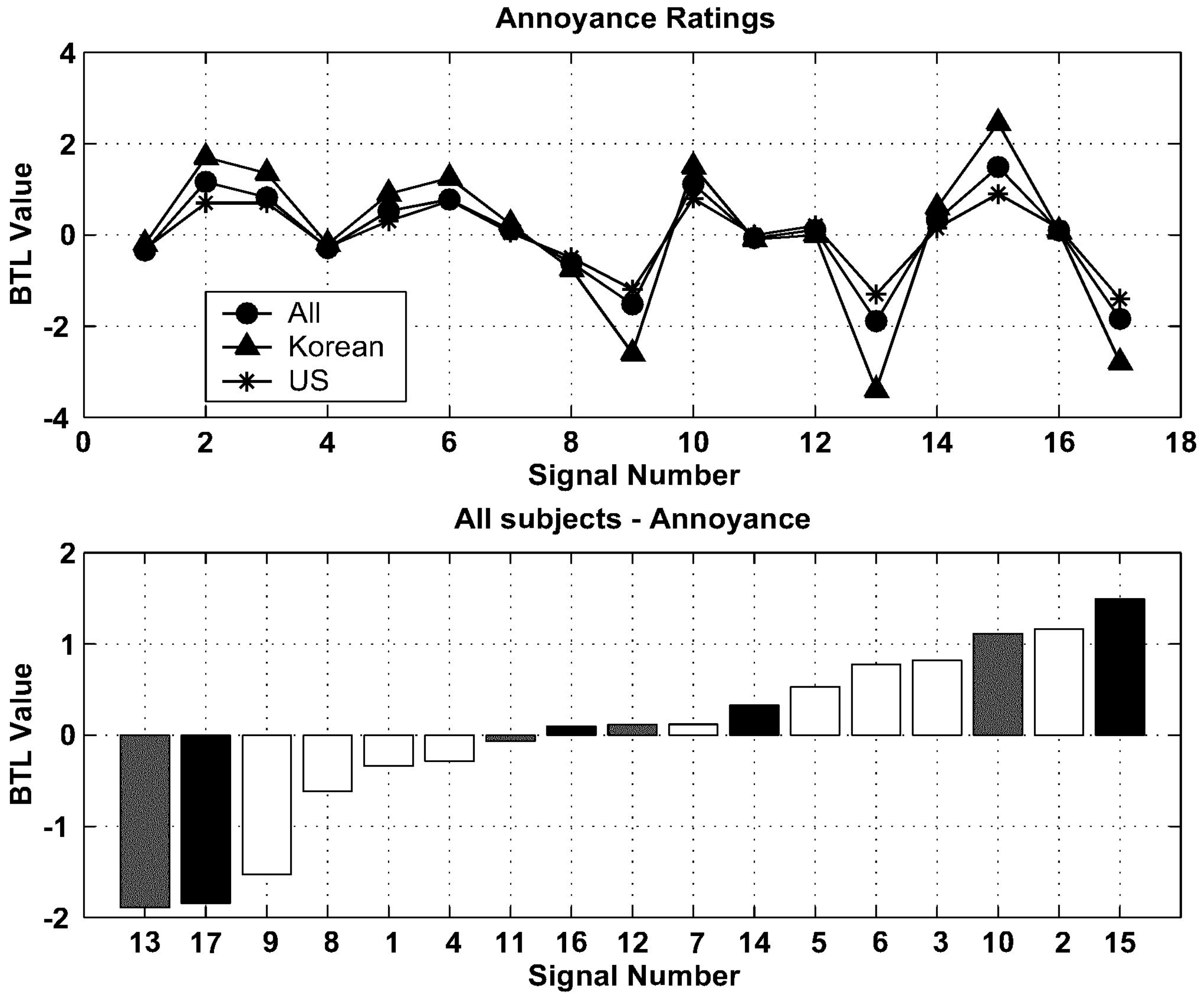

Figure 1: Subjective response data after transformation to BTL scaled values; upper plot: BTL values from all responses, Korean subjects' responses and US subjects' responses; lower plot: the annoyance ratings generated from all subjects, ordered from least to most annoying.

3 - OBJECTIVE ANALYSIS AND SINGLE METRIC MODELS

Several sound quality metrics [12] were calculated by using the Bruel and Kjaer Sound Quality Program Type 7698 version 2.00.01. The metrics are shown in Table 2. N is stationary loudness as calculated from using ISO 532B, the TL and IL metrics refer to nonstationary loudness calculations, TL takes into account temporal masking and IL does not. Both Zwicker (Z) and Aures (A) Sharpness (S) were calculated. Various statistics were calculated: mn-mean, sd-standard deviation, max-maximum, numbers − metric values exceeded that percent of the time. Roughness (R), Fluctuation Strength (F), Tone to Noise Ratio (TTN) and Prominence (Prom) were also calculated.

The metrics were used as predictors of annoyance and the resulting R^2 values are shown in Table 2. Single metric models where the probability that the model occurred by chance is greater than 0.02 are shown in italics. The ordering of the metrics from best to worst predictors, shown in brackets in the Table 2, for the Korean and US responses are very similar. With the exceptions of standard deviations for TL and IL and standard deviations and maximum levels for sharpness, the families of metrics are in the order: statistics of Aures Sharpness, Loudness, IL and TL, Zwicker Sharpness.

METRIC	**R^2 (ORDER) KOREAN**		**R^2 (ORDER) US**		**METRIC**	**R^2 (ORDER) KOREAN**		**R^2 (ORDER) US**	
SPLA - dB(A)	*0.32*	*(25)*	*0.26*	*(25)*	**SmaxZ - acum**	**0.43**	**(23)**	**0.45**	**(21)**
SPL - dB	*0.06*	*(30)*	*0.03*	*(30)*	**SmnZ - acum**	**0.46**	**(21)**	**0.51**	**(18)**
N - sones	**0.74**	**(5)**	**0.69**	**(5)**	**SsdZ - acum**	**0.34**	**(24)**	**0.31**	**(24)**
Tlmax - sones	**0.64**	**(15)**	**0.56**	**(16)**	**S1Z - acum**	**0.48**	**(17)**	**0.51**	**(19)**
TLmn - sones	**0.74**	**(6)**	**0.69**	**(6)**	**S5Z - acum**	**0.47**	**(19)**	**0.50**	**(20)**
TLsd - sones	*0.26*	*(27)*	*0.18*	*(27)*	**S10Z - acum**	**0.47**	**(18)**	**0.51**	**(17)**
TL1 - sones	**0.64**	**(14)**	**0.56**	**(15)**	**SmaxA - acum**	**0.61**	**(16)**	**0.59**	**(14)**
TL5 - sones	**0.70**	**(11)**	**0.63**	**(11)**	**SmnA - acum**	**0.88**	**(1)**	**0.88**	**(1)**
TL10 - sones	**0.72**	**(9)**	**0.65**	**(9)**	**SsdA - acum**	**0.47**	**(20)**	**0.45**	**(22)**
ILmax - sones	**0.68**	**(12)**	**0.59**	**(13)**	**S1A - acum**	**0.81**	**(4)**	**0.80**	**(4)**
ILmn - sones	**0.74**	**(7)**	**0.68**	**(7)**	**S5A - acum**	**0.83**	**(3)**	**0.82**	**(3)**
ILsd - sones	**0.45**	**(22)**	**0.38**	**(23)**	**S10A - acum**	**0.84**	**(2)**	**0.84**	**(2)**
IL1 - sones	**0.67**	**(13)**	**0.60**	**(12)**	*R - asper*	*0.26*	*(26)*	*0.25*	*(26)*
IL5 - sones	**0.71**	**(10)**	**0.65**	**(10)**	*F- vacil*	*0.08*	*(29)*	*0.04*	*(29)*
IL10 - sones	**0.72**	**(8)**	**0.66**	**(8)**	*TTN - dB*	*0.21*	*(28)*	*0.17*	*(28)*
					Prom - dB	*0.01*	*(31)*	*0.02*	*(31)*

Table 2: Coefficients of determination (R^2) for single metric regression models for the two populations; numbers in brackets indicate ranking of model; italic indicates p > 0.02.

4 - MULTIPLE METRIC MODELS

Two and three metric linear regression models were constructed using all possible combinations. The best models were then examined more closely. The correlation between metrics were used to decompose the models into components to determine the role that each sound characteristic, as measured by the metric, is playing in refrigerator noise annoyance. The results are shown in Figure 2 for the model containing stationary Loudness (N), mean Zwicker Sharpness (SmnZ), and mean Total Loudness (TLmn). The black section is the part that could be due to Loudness or to Sharpness, the dark gray section is the part purely due to Loudness, and the light gray section is purely due to Sharpness. The white sections are the parts that are purely due to the inclusion of the TLmn metric, and the dots are the BTL scaled values offset by a constant. The minimum contribution of each of these components has been removed. Models were also estimated from the Korean only and US only populations and these are shown in Equations (1) and (2). SmnZ:mod is mean Zwicker Sharpness with the dependence on Loudness for this signal set removed. TLmn:mod is the mean of Total Loudness with the contributions of Loudness and Sharpness removed.

$$\text{Korean}: \ \text{BTL} = (-9.0 + 0.5\text{N}) + (-4.0 + 3.9\text{SmnZ}:\text{mod}) + (-1.5 + 3.6\text{TLmn}:\text{mod})\,; \ \left(R^2 = 0.98\right) \tag{1}$$

$$\text{US}: \ \text{BTL} = (-3.9 + 0.2\text{N}) + (-2.0 + 2.0\text{SmnZ}:\text{mod}) + (-0.7 + 1.7\text{TLmn}:\text{mod})\,; \ \left(R^2 = 0.97\right) \tag{2}$$

Dividing (1) by the 2.2 scaling mentioned above, results in a predicted US model:

$$\text{BTL} = (-4.0 + 0.2\text{N}) + (-1.8 + 1.8\text{SmnZ}:\text{mod}) + (-0.7 + 1.6\text{TLmn}:\text{mod}) \tag{3}$$

which is very close to the model generated directly from the US responses, Equation (2). There is a slightly smaller contribution from Sharpness (1.8 versus 2.0) but this may not be significant.

5 - CONCLUDING COMMENTS

For the set of seventeen sounds used in the test, A-weighted sound pressure level was not a useful metric to discriminate between sounds. For a more general-purpose refrigerator noise model this may not be true, however, when similar capacity refrigerators are being compared for sound quality this may often be the case. Loudness and spectral balance were the two key components in regression models used to predict annoyance. Korean subjects responded more strongly than US subjects but little differences were observed in the ordering of the sounds in terms of annoyance, or between the sets of metrics in the models that best predicted the responses. There is perhaps evidence that US subjects weight Sharpness slightly more than Korean subjects, but this needs to be substantiated with further research using a much larger subject population and more signals. Clearly from the results shown, noise control efforts focused on reducing Loudness at the expense of increasing Sharpness may be counter productive.

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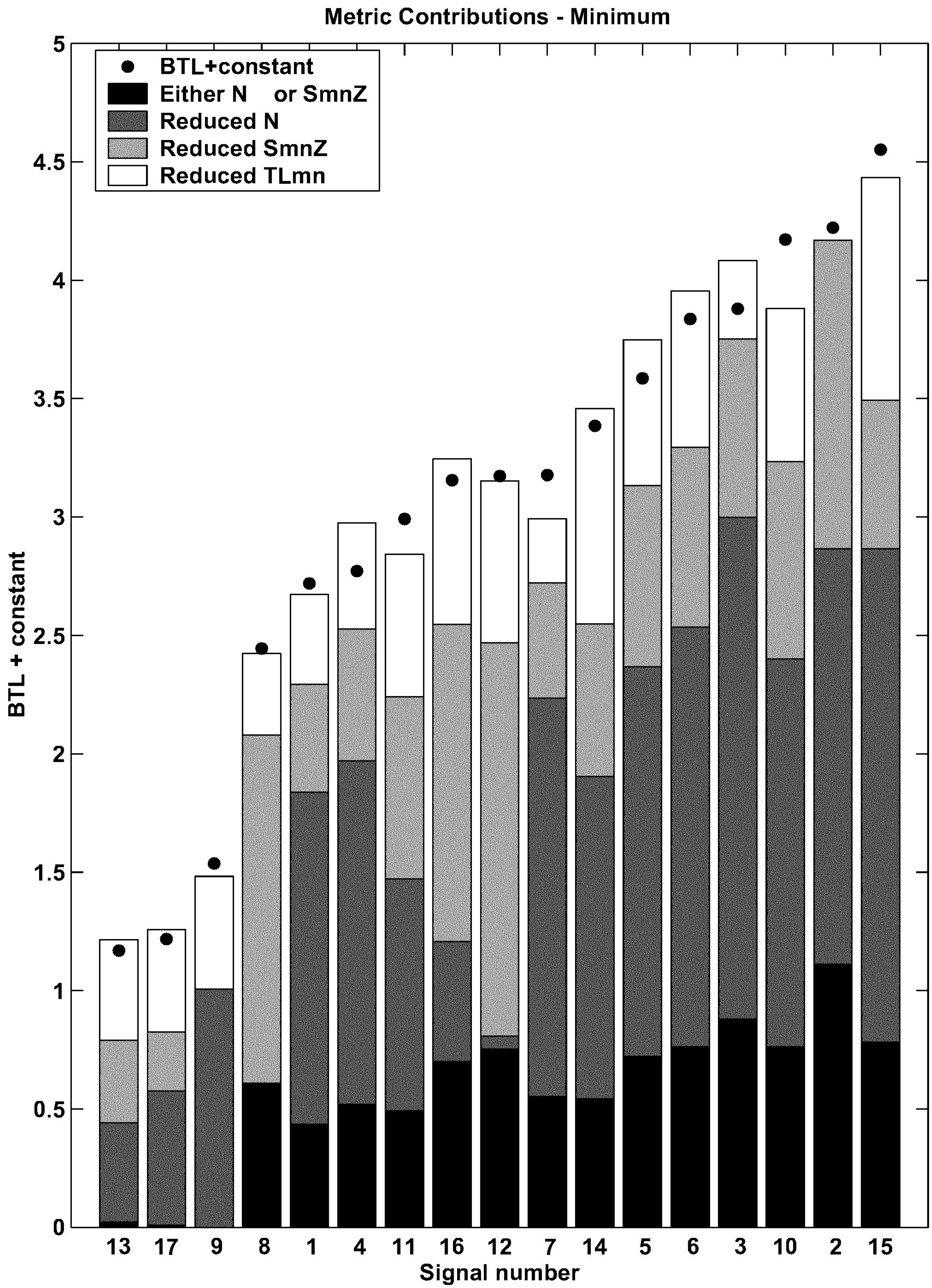

Figure 2: Predicted BTL values adjusted by a constant; model subdivided into parts, which may be attributable to either sharpness or loudness, loudness only, sharpness only, and mean total loudness only; R^2= 0.98.