Vibrational Influence on Product Sound Quality in Cars

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Previous research has suggested that the cross-modal effects of vibrations on perception of sound is a relatively persistent phenomena. The current paper focus on how vibrations influence judgments of Product Sound Quality. In an experiment vibrational and auditory stimuli were presented to listeners seated in an experimental car. The stimuli used were recordings of an idling car, and a car passing a joint to a bridge. Both recorded binaurally parallel to accelerometer signals for the steering wheel and the seat. The stimuli was modified in a systematic way and presented to 44 participants.

The results showed a strong influence of vibration on sound perception, both for steady state and transient sound/vibrations. Furthermore it seems like preference for vibration were dependent on the situation that the stimuli normally is experienced in. Implications for Product Sound Quality testing and sound design is outlined.

1 Introduction

When designing for Product Sound Quality (PSQ), it is of importance to consider many aspects of the product, which is said in this quotation.

"Product-sound quality is a descriptor of the adequacy of the sound attached to a product. It results from judgements upon the totality of auditory characteristics of the said sound – the judgements being performed with reference to the set of those desired features of the product which are apparent to the users in their actual cognitive, actional and emotional situation." (Blauert & Jekosch, 1997)

In this paper the focus is on the vibrational influence on sounds in cars, that is the test stimuli consisted of both sound and vibration, but participants were explicitly asked to rate the sound only. This experimental paradigm gives the opportunity to look further into PSQ and how non-auditory features may modulate sound perception [1]. If vibrations have a systematic effect on sound perception this knowledge may be used when designing sounds for a specific application or context (i.e. car sounds).,

2 Psychoacoustic testing

2.1 Test design

The test design was a traditional absolute judgement where the participants were asked to fill in a written questionnaire after having listened to/experienced each stimuli. To eliminate effects of order and learning the sequence of the stimuli was randomized and also used backwards. In the test there where 10 stimuli (sound+ vibration) in the test but only the seven presented earlier was used for this analysis. The questionnaire had 12 questions, where eight where questions on how well the sound (not the stimuli) corresponds to an adjective on a scale from 0 to 8. The adjectives were taken from previous research [2, 3]. In the present analysis the five adjectives presented in Table 1 were used. The test was performed in Swedish and all the test participants were Swedish speaking.

Table 1: Adjectives used in the analysis

English	Swedish
Powerful	Kraftfullt
Unpleasant	Obehabligt
Rough, Roughness	Rått, Råhet
Attention Demanding	Uppmärksamhetskrävande
Desirable	Önskvärt

2.2 Stimuli

Two sets of stimuli were used, both recorded using calibrated equipment from HEAD Acoustics. The signals recorded were Binaural sound parallel to seat and steering wheel vibrations.

The first set of stimuli was a recording of a passenger car during wide open throttle acceleration (WOT). This is a situation where vibrations from the engine and transmission often are clearly present, and the vibrations probably are of importance for the perception of sound character and sound quality of the car. From this recording three stimuli was created, all of them leaving the sound as it was recorded in the car.

1. without vibrations
2. with unmodified vibration
3. vibration level increased by 5dB

The second set of stimuli was also a passenger car passing a joint to a bridge under constant speed. This resulted in a "clonk" sound. From this recording 4 stimuli was created, also here the sound was left as it was recorded. The stimuli created was

1. without vibration
2. vibration level decreased by 5dB
3. unmodified vibrations
4. vibration level increased by 5dB

2.3 Test facilities

The test was performed in a SoundCar [Head], a car with shakers attached to the seats and steering wheel, a subwoofer in the trunk, and the main part of the sound presented over headphones. This facilitates calibrated playback of sounds and vibrations to the test persons. The car was placed in a room with some damping materials on the walls and a blank white screen placed on the wall in front of the car. The test persons where seated in the drivers position while the test leader was seated in the passenger seat, giving instructions and handling the playback of the stimuli. The advantage of using a setup like this is that it makes it easier for the participants to rate the sound in a more realistic context, which should result in more reliable results and better validity for the study.

2.4 Participants

In the test 44 persons participated in the test, all employees at Volvo Car Corporation, 52% working in the Noise and Vibration Center. The mean age was 39 years, with std. Dev of 9.2. There were 23% women and 77% men in the test. Of all participants, 52,3% works at Noise- and Vibration centre. Participants volunteered for participations during their normal working hours and did not get any special economic compensation for participating in the test.

3 Results

The analyses performed were both MANOVAs to check for overall difference as well as individual post-hoc comparisons. The results for the two different series (WOT and Transient) will be presented separately.

3.1 WOT stimuli

A strong main effect could be shown for the Wide Open Throttle stimuli; $F(2,86)=25.938$, $p<.001$. Comparing pairwise, not all pairs showed significant difference. This results are presented in the following list. The absolute ratings are presented in Figure 1 and Figure 2.

- For *Powerful* and *Rough*, the stimuli without vibrations showed a significant difference (95%)from the ones with vibrations, while no difference could be seen between the ones with vibrations.
- For *Attention demanding* and *Unpleasant* all combinations of the WOT stimuli showed significant difference (95%).
- For *Desirable* the stimuli with increased vibrations differed from the other two.

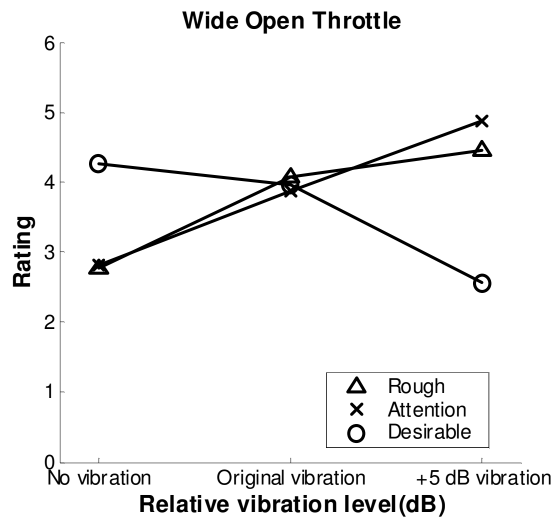

Figure 1: Ratings of the WOT stimuli on three adjectives

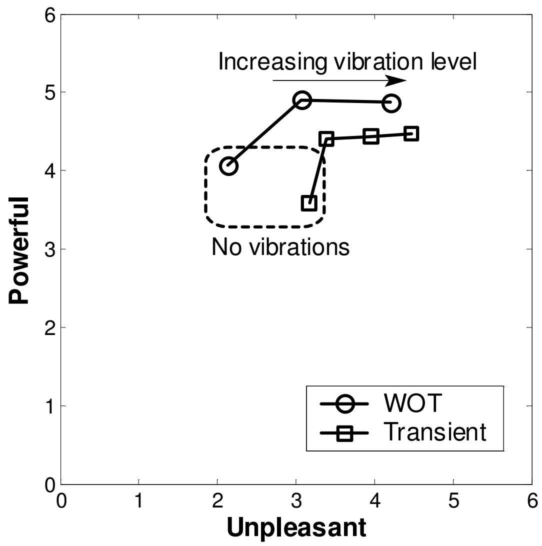

Figure 2: Ratings on Powerful and Unpleasant for both WOT and Transient stimlui series. The series are as presented in chapter 2.1

3.2 Transient stimuli

For the transient stimuli the main effect was F(3,129)=12.808, p<.001, and thus the stimuli were not the same.

- For *Powerful*, also for this set of stimuli, the rating of the sound for the stimuli without vibrations was rated lower than the ones with vibrations. No other significant difference could be shown.
- For *Unpleasant,* the stimuli without vibrations separates from the one with original vibrations and the one with increased vibrations. The stimuli with decreased vibrations differs from the one with increased vibrations, but other significant differences could be shown.
- For *Rough,* the stimuli with original vibrations and increased vibrations separate from each other and the rest of the stimuli, while no other difference could be seen.
- For *Attention Demanding,* the sound with increased vibrations was the only one that significantly could be differed from the others.
- For *Desirable*, the stimuli without vibrations differs from the one with increased vibrations, and the stimuli with decreased vibrations differs from the stimuli with original vibrations and the one with increased vibrations.

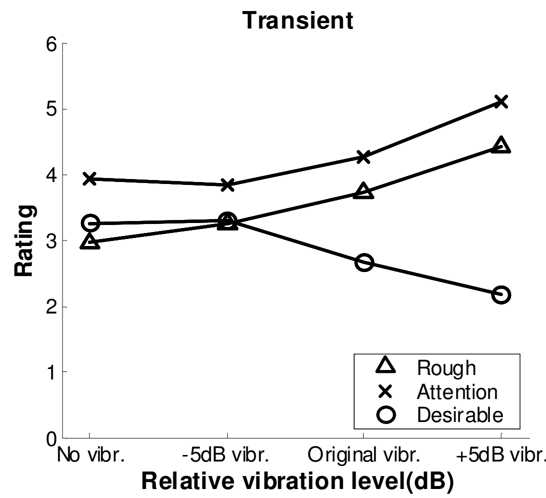

Figure 3: Ratings of sound for the transient stimuli

4 Discussion

In line with previous research, the current results shows that the vibration level is of importance for the perception of sounds. For the adjective powerful it seems like the mere presence of vibrations is important, while the level of the vibrations matters less for perception. For the adjective unpleasant on the other hand the level matters, it shows an increment with increasing vibration level. These two descriptors have in previous research to be of great importance for interior car sounds [bisping], note that we here used unpleasant instead of pleasant, so to make direct comparisons the scale must be inverted. Attention demanding showed pattern similar to unpleasant with a correlation .718 (p<.001). This can be an effect called the mismatch effect [4], that the increment of vibrations in the stimuli makes in perceived as two different percept, and not sound and vibration as one unit. Desirable shows a negative trend to Unpleasant as expected, but also to Attention demanding, especially for the stimuli with vibrations. This is also due to the effect that the the stimuli is perceived as two separate percept[4].

The rated roughness of the sounds correlates around .5 to unpleasant, attention demanding and powerful, but only -.2 to desirable. This implies that the roughness of the sound is of interest but that there are other aspects to take into account to measure how powerful a sound is. Perhaps designing psychophysical metric using both sound and vibration.

Taken together, these results suggests that to optimize a car on the sound character of powerful, but not making it unpleasant, the optimum vibration level would be somewhere where the knee of the curves in Figure 2 would be with a higher resolution in the test design. Further investigation of this area is thus of interest.

References

[1] D. Västfjäll, '*Affect as a Component of Perceived Sound and Vibration in Aircraft*'. Chalmers University of technology 2003, Gothenburg Sweden, ISSN 0346-718X

[2] A. Sköld et. al. '*Perceived Sound Character and Objective Properties of Powertrain Noise in Car compartments*' Acusticaunited with Acta Acustica, vol 91, pp.349-355

[3] R. Bisping, '*Car Interior Sound Quality: Experimental Analysis by Synthesis*', ACUSTICA acta acustica, Vol.83 (1997) pp.813-818.

[4] D. Västfjäll, '*Cross-modal interaction between aural, tactile and visual senses: sound quality evaluation using a virtual aircraft*' Journal of sound and Vibration, in press.