Annoyance Perception of Dishwasher Noise

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Introduction

Increase in industrialization and expanding large urban complexes make noise an ever-increasing problem. There have been always different studies trying to set up legislative measures against noise, with the clear distinction that the subjective evaluations of noise, hence annoyance, is different than pure physical measurements. These evaluations on annoyance usually been investigated first in the field of industrial noise as well as transportation noise. [1] On the other hand, annoyance has also been used thoroughly in the Sound Quality studies in different branches for different equipment. Annoyance has been used to distinguish the quality attributes of the attached sounds to a product

In Fastl's study with electric razors, where the original levels have been used, it is usually observed that the loudness has dominating effect on annoyance estimations [2]. Whereas, Schell-Majoor [3] use stimuli with equalized loudness values since the main aim is to concentrate on the other aspects of sound quality rather than dominant loudness effect. Dominance of loudness on annoyance estimations is a known phenomenon.

Considering this fact that, it has been discussed in the study of Dittrich and Oberfeld [4] that the subjects might not be evaluating annoyance, rather than purely concentrating on loudness when it is asked to judge repeatedly the same type of stimuli. This leaves a big problem for the Sound Quality studies, if the subjects are able to distinguish loudness with annoyance, and eventually, how to model overall annoyance perception of household appliances.

Within this study, two different listening tests, namely stimuli of dishwasher noise with original level and equalized level are conducted and the results are compared each other. It has been discussed the possibilities of an overall annoyance model of dishwasher noise.

Noise Generation Mechanisms of a Dishwasher

A dishwasher is composed of mainly three components. First one is the tub where the washing takes place. Tub is usually covered with the vibration dampening bitumen material from the outside, which the position, thickness and the amount of bitumen used in a dishwasher varies amongst different brands and different designs. Secondly the enclosure surrounds the metal tub giving the dishwasher its final look. User interface takes place in the enclosure, with the accompanying electronics is placed between tube and the enclosure. Between the enclosure and the tub usually lies also the sound absorbing material. In some of the designs, enclosure side panels have different rib designs to change their modal characteristics also varying between brands and units. Lastly, usually for a free standing, integrated or half integrated dishwashers, mechanical elements lies underneath the tub, such as inlet and outlet pumps, water tank, heater, water softener etc.

Water is pumped to the different spray arms by the inlet pump and the spray arms rotate due to the water pressure generating momentum. This phenomena generates a direct structure-borne transmission path originating from the vibrations from pump and transmitting through the mountings of machine elements. Moreover to this structure-borne path, also direct airborne noise path can be named, basically noise emitting from the pump reaching the listeners position through direct airborne path. Lastly, subjects usually define the noise of the dishwasher as being 'splashing' which emphasizes the main component of water splash noise [5].

From these perspective, it is possible to roughly categorize the noise emitting from a dishwasher into three main groups, low frequency humming noise coming from the pump, noise originating from the transmitted vibrations to the plates of which the frequency content can be tailored by changing the plate parameters and lastly the mid to high frequency splashing noise (especially with higher frequency content for the cases with less vibration isolation in tub) due to the water splash which is intermittent, repetitive and impulsive. For the case of drying, also some high frequency tonal components usually occurring from the drying fans can also be added as an extra characteristic accompanying to the washing noise characteristics.

Methodology

In this study, different dishwashers are recorded in same acoustical conditions and technical conditions (such as inlet water pressure and with/without any dishes etc.) Obtained recordings are investigated by an expert panel to obtain the representative sample stimuli for each device corresponding the washing and drying phases. The selected representative stimuli is 5 seconds, which helps to conduct proper listening experiments still showing the repetitive impulsive characteristics of washing noise.

Selected representative samples then are used for successive listening tests. Not only the real recorded stimuli but also the altered recordings are used for listening tests. Psychoacoustical parameters are also calculated for the sample stimuli and especially for the second listening test, in which the loudness equalized stimuli are used, effect of different listening test methodologies are investigated.

At the end, correlations between annoyance estimations obtained from the listening tests and the acoustical and psychoacoustical parameters are obtained, to understand the dynamics of annoyance perception of dishwasher noise, which can give us clues about the possible sound engineering in the future productions.

Dishwasher Recordings and Stimuli Generation

Dishwasher recordings are conducted in a semi-anechoic room with reflective floor surfaces. For the sound quality studies, a "user-position" is defined which is 1m away from the dishwasher and 1.6m height (Figure 1). All the dishwashers are recorded in fully-loaded case with most possible surface coverage of baskets using the standardized dishes. During the recordings, a MDF housing is used which has been defined in EN 60704-2. Inlet water pressure is controlled with a pressure regulator at kept at 3 bars. Since the washing algorithm has a relatively big impact on the emitted sound, standardized ECO washing program is used for all the recordings, in which the water temperature is usually kept at 50°C and this program is usually used for any official declarations of sound power level estimations.

Recordings of all the dishwashers show that there are three distinctive sound events during an overall working cycle, in terms of acoustical characteristics. First one is the water drainage, which usually happens once at the beginning and two or three times during the washing cycle depending on the brand and washing algorithm. Second portion is the washing cycle, and third one is the drying cycle. Water drainage has a distinctive noise characteristics since the drainage pump usually louder than the inlet pump. However, the overall duration of water drainage is relatively short in comparison to the duration of washing cycle and drying cycle. Hence, this portion is not taken into account within this study. Washing cycle has relatively quasi-stationary characteristics, still having differences over time, depending especially on the RPM values of the water pump used to drive the arms and the spray arm which is being used at this point. Hence, it is not acoustically possible to select one representative sound sample which corresponds to the all washing cycle. Hence, different 5 seconds portions are cut from the whole recordings and each portion is compared with another one, based on the expert panel subjective evaluation as well as its levels, frequency content and psychoacoustical parameters. After this iterative comparison procedure, some representative 5 second stimuli are selected from the washing cycle of each recorded device. Lastly, drying section is relatively stationary and quiet in comparison to the washing cycle, but still having tonal components which can make the sound relatively annoying according to the participants. For this stationary session of drying, one representative 5 second sample is selected for each recorded dishwasher.

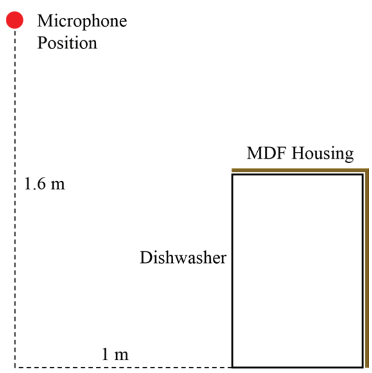

Figure 1: Microphone positioning, dishwasher and MDF housing

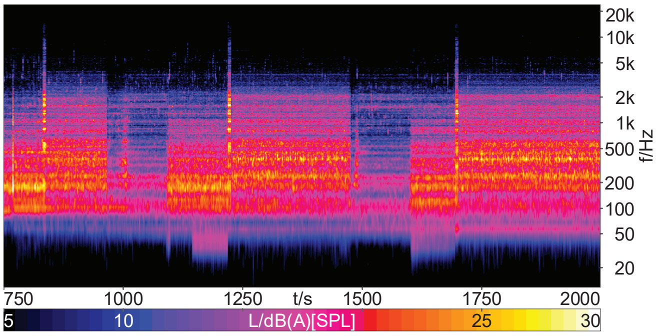

Figure 2: Example spectrogram of a washing cycle, including the three different spray arm periods repeating each other (A-weighted, Spec. Size: 4096)

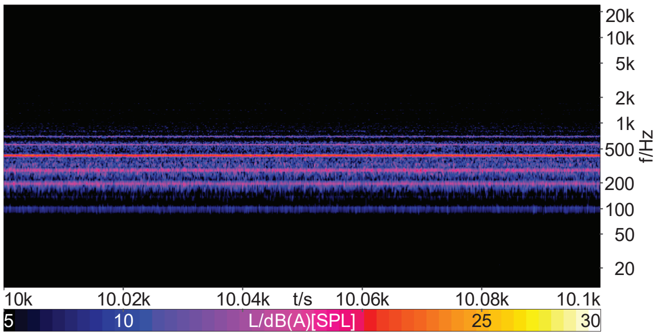

Figure 3: Example spectrogram of a drying cycle, tonal components coming from fan noise (A-weighted, Spec. Size: 4096)

Listening Tests

Two separate listening tests have been conducted through this study. Main difference between the two listening tests is the listening test 1 includes the stimuli in their original level, whereas in the listening test 2 A-weighted sound level of the stimuli is equalized.

Main idea of this two-step procedure is to understand the effect of the loudness on the annoyance perception of dishwasher noise and how much variation in annoyance estimations can be explained by the variations in loudness. If the loudness is dominating/spoiling the annoyance estimations, keeping it out shouldn't be a real solution for modelling, since loudness is still a really important parameter and keeping the loudness out of the investigation set cannot really represent the real dynamics of annoyance estimations.

Totally 38 different stimuli obtained from 10 different dishwashers have been used in the both listening tests including representative samples both from washing and drying phases. Used representative stimuli have the duration of 5 seconds.

16 different subjects (6 female – 10 male) are attended both of the listening tests, with a pause in between the successive tests to make sure that no biased information should be transferred from one test to another. Mean age of the participants is 36, ranging from 25 to 57. None of the participants is observed to have hearing loss.

Perception experiments are conducting in a sound attenuating room, considering the fact that the investigated stimuli have relatively low loudness values. Every stimuli is presented in random order through Sennheiser HD600 headphones and some stimuli is selected as training including the extremities of the stimuli pool so that the subjects can get familiar with the investigated borders. Every stimuli is presented three times to check inter-individual validity. Subjects are asked to evaluate the annoyance of the dishwasher noise using a category scaling on a quasi-continuous scale (from 0 to 100) with equidistance neighboring categories (not at all, slightly, moderately, very, and extremely)

Normal distribution of the annoyance estimations amongst test subjects is observed on more than %95 of the stimuli for both listening tests according to the Shapiro-Wilk test. Skeweness and Kurtosis values are also acceptable for all stimuli in both listening tests, hence the mean values and standard deviations of annoyance estimations are calculated for each stimuli in both of the listening tests.

Psychoacoustical Parameters

A-weighted sound levels as well as loudness, sharpness and roughness values are calculated for each stimuli set used in listening tests. For the original stimuli and the equalized stimuli, mean values of the aforementioned parameters as well as max and min values for both listening tests are given in Table 1. More detailed information on the distribution of the parameters in boxplots can also be seen in Figure 4. It can be seen that, variation of the overall level, hence the loudness is decreased in high amount. However, even if it is not in the same degree, decrease in the roughness can also be observed, which shows the fact that parameters which are considered to describe the overall annoyance estimations are up to some degree cross correlated. It is not possible to decrease the loudness by keeping the sharpness and roughness exactly constant, since the definition of these parameters are inherently correlated.

Correlations between the annoyance estimations and the calculated parameters for both listening tests are given in Table 2 and

Table 3. Significant correlations between annoyance and the calculated parameters are highlighted.

Table 1. Distribution of calculated parameters amongst different listening tests

	Original			Equalized		
	Mean	Max	Min	Mean	Max	Min
dB(A)	31.3	42.3	25.3	30.6	31.6	30.2
Loudness [soneGF]	1.67	4.45	0.63	1.47	1.82	1.13
Sharpness [acum]	1.23	1.64	0.88	1.21	1.75	0.79
Roughness [asper]	0.14	0.35	0.04	0.12	0.16	0.09

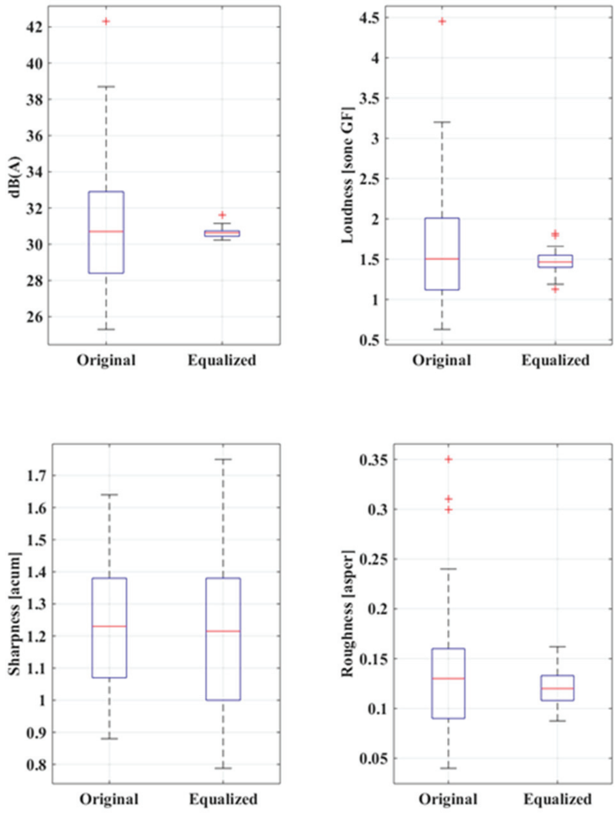

Figure 4: Boxplots for distribution of calculated parameters amongst stimuli for both listening tests

Table 2. Correlations between annoyance estimations and calculated parameters; first listening test with original level

	Pearson Correlation			
	Annoy.	Loudness	Sharpness	Roughness
Annoyance	1,0	,905**	-0,3	,751**
Loudness		1,0	-0,1	,909**
Sharpness			1,0	-0,1
Roughness			-0,1	1,0

**. Correlation is significant at the 0.01 level (2-tailed).

Table 3. Correlations between annoyance estimations and calculated parameters; second listening test with equalized level

	Pearson Correlation			
	Annoy.	Loudness	Sharpness	Roughness
Annoyance	1,0	0,1	-,420**	-0,1
Loudness		1,0	,417**	0,2
Sharpness			1,0	-0,2
				1,0

**. Correlation is significant at the 0.01 level (2-tailed).

Results and Discussions

Annoyance estimations for the 38 stimuli in both listening experiments are given in Figure 5. Stimuli 1 is selected here as the anchor value for the equalization procedure, implying that the level of stimuli 1 has not been changed for both of the listening tests. However, there is still a slight difference between the both results for Stimuli 1, stressing out the fact that the result of the sound quality studies are definitely depends on the selection of stimuli pool. Here it can be seen that, for most of the stimuli, loudness equalization yields in increased annoyance estimations. However, a specific trend amongst the all other stimuli is not observed. On the other hand, when the distribution of annoyance estimation mean values amongst different stimuli is observed for both of the listening tests, it can be seen that the listening test 2 has not so much deviation in the annoyance estimations. This phenomena is shown in Figure 6. For the equalized stimuli, although there are deviations in the separate evaluations in each stimuli, the mean values of the all annoyance estimations stays around 50. That might imply two important results, either it was not possible for the subjects to distinguish the annoyance differences between stimuli, or the effect of loudness is really critical in dishwasher annoyance estimations, such that the equal loudness yields in almost equal annoyance evaluations.

For the listening test 1, correlation values in Table 2 shows that annoyance values highly and significantly correlated with loudness and roughness. However, roughness, as the definition implies, reflects also the variation in loudness, hence the correlation between the loudness and roughness turned out to be highly significantly correlated. Loudness and roughness seem to be repeated cross-correlated inputs. It can be deduced that the annoyance estimations are solely based on loudness values.

One question is still open and needs to be investigated. For the first listening test, it is found out that the loudness can explain the %82 of the variation in the data while sharpness can %9. In the second listening test, sharpness can explain the almost %17 percent of the variation in the data. If we try to build a model of dishwasher noise annoyance, should the sharpness play a role in %17 percent variation or %8? The findings are compatible with [2], that the loudness should be included in sound quality studies for inclusionary approach, having the risk of misunderstanding between loudness and annoyance mentioned in [4] in mind. Not a single listening test, but a successive listening tests structured in factorial design should be conducted to get overall annoyance estimations.

As a further study, it needs to be investigated in detail, for each stimuli and/or stimuli groups, how the level equalization changes the overall annoyance estimations in comparison to the change in other acoustical psychoacoustical parameters. Other effects especially related to time structure might also be investigated and new parameters should be defined to reflect this time effect in annoyance estimations.

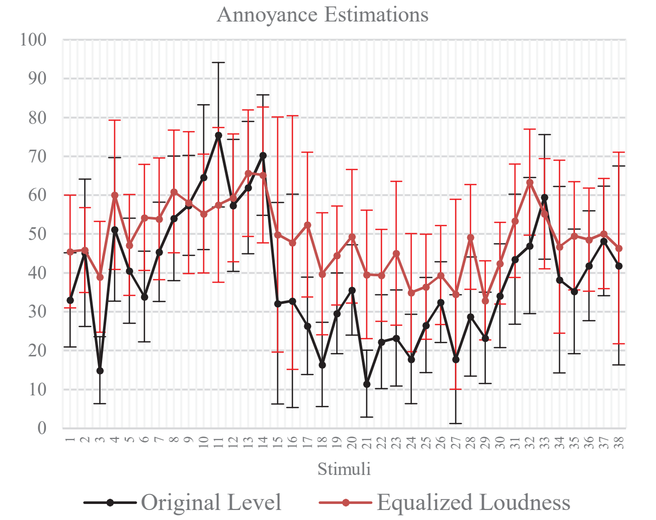

Figure 5: Results of both listening tests, mean values and standard deviations

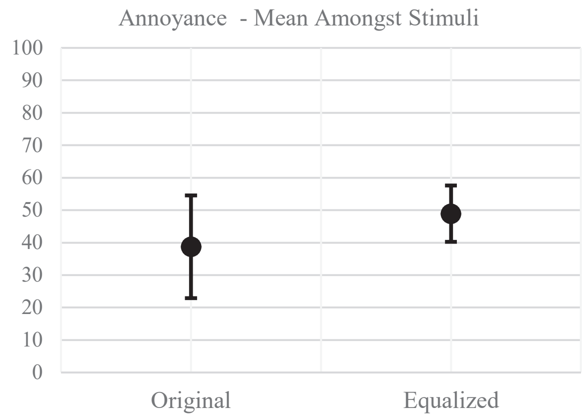

Figure 6: Distribution of mean annoyance estimations amongst 38 stimuli and the standard deviations of mean values, for both listening tests.

References

[1] Marquis-Favre, C., Premat, E., Aubrée, D. (2005). Noise and its effects–a review on qualitative aspects of sound. Part I: Notions and acoustic ratings. Acta acustica united with acustica, 91(4), 613-625.

[2] Fastl, H. (2000). Sound Quality of Electric Razors - Effects of Loudness. InterNoise 2000, Nice, France.

[3] Schell-Majoor, L. (2018). Objective Quality Assessment of Product Sounds. Dissertation, Carl von Ossietzky Universität Oldenburg.

[4] Dittrich, K., Oberfeld, D. (2009). A comparison of the temporal weighting of annoyance and loudness. The Journal of the Acoustical Society of America, 126(6), 3168-3178.

[5] Atamer, S., Altinsoy, E., Hirschfeld J. (2019). Vibro-Acoustical Analyses of a Dishwasher, DAGA 2019, Rostock, Germany