Effects of Frequency on Annoyance Caused by Motorcycle Noise

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Introduction

Motorcycles are one of the main sources of traffic noise emission. Considering that emitted noise from motorcycles is extremely annoying, it is essential to study the influencing parameters which might cause annoyance. Various motorcycles generate noise in different frequency ranges. Although emitted noise with higher frequency content can be more annoying, the lower frequency noise can be heard farther away from the noise source. This study aims to investigate the relationship between the frequency content of the motorcycle noise and the resulting annoyance. For this purpose, noise recordings for various types of motorcycles were carried out. The recordings were then used for conducting a perceptual experiment to realize the annoyance caused by each stimulus. Eventually, the results of the perceptual experiment are utilized to determine the effect of the frequency range on participant's annoyance. Moreover, the psychoacoustic parameters related to each stimulus are analyzed and a conclusion is drawn to show which parameters in motorcycle noise exacerbate the annoyance.

A range of different parameters can cause and alter the annoyance caused by noise exposure. Annoyance caused by traffic and vehicle noise depends on many parameters, such as frequency of the emitted sound, vehicle speed, road condition, traffic density, etc. The relationships between traffic density, pavement, and vehicle speed with annoyance have been addressed in some studies [1][2]. Moreover, annoyance depends on the category of the vehicle which is emitting the noise. Powered two wheelers and motorcycles are considered as extremely annoying sources of noise. The contribution of this category of vehicles on annoyance has been extensively analyzed [3][4][5]. The aim of this study is to investigate how the frequency range of the emission and the tonal components of the emitted sound can alter the resulting annoyance.

Methodology

In order to investigate the annoyance caused by motorcycle noise, six motorcycles (motorcycles A to F) were chosen. The measurements have been conducted in idle and accelerated states for these motorcycles. Afterwards, the spectral characteristics, psychoacoustic parameters, and tonal components of various machines were compared and, based on the results of the listening test, a connection between the frequency behavior of the motorcycles and the resulting annoyance has been drawn. Eventually, Pearson correlation method was utilized to specify the correlation between the psychoacoustic parameters and annoyance.

Measurements

For the measurements of the chosen motorcycles, binaural measurement technique was used. The measurements for two working states (idle and accelerated) were carried out to study how the annoyance of one specific motorcycle in different states varies. The measurement tool used in this study was SQuadriga II, and for data analysis ArtemiS SUITE software was utilized. The frequency responses of all motorcycles are shown in Figure 1. It can be seen that various motorcycles have different spectral behaviors at various frequency ranges. In the following, the effects of these differences on the annoyance perceived by individuals are investigated.

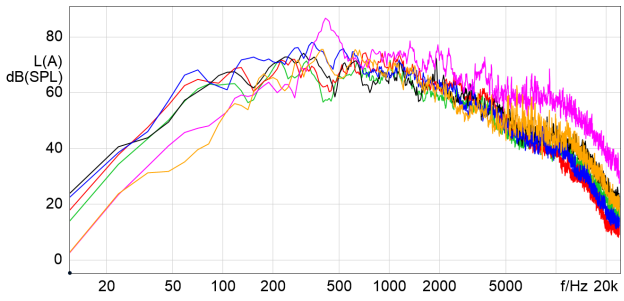

Figure 1: Frequency responses of the motorcycles under the study.

Listening Test

The recorded sounds from the motorcycles were used in a listening test where participants could rate their annoyance responses for each stimulus. In total, 25 participants took part in the listening test. Participants were between 26 to 61 years old with the average age of 36.2 years old. The percentages of male and female participants were respectively 56% and 44%. Participants could rate their annoyance level for each stimulus in a range from not annoying at all to extremely annoying. For data analysis, this verbal scale was later transformed to a numerical scale from 0 (not annoying at all) to 10 (extremely annoying). The scale bar used in the listening test for rating the annoyance is shown in Figure 2.

Figure 2: Scale bar for annoyance estimation used in the listening test.

The results of the listening test are illustrated in Figure 3 where annoyance responses towards all simuli in both idle

and accelerated working states are depicted. The boxplots for accelerated state are specified with (a) for each motorcycle. The results show that the annoyance ratings vary considerably from idle to accelerated state. Furthermore, all motorcycles are perceived as more annoying in the accelerated state. Moreover, the distribution of the responses varies from one motorcycle to another. For some stimuli, the ratings are distributed in a wider range while for some others the responses are accumulated in very small ranges.

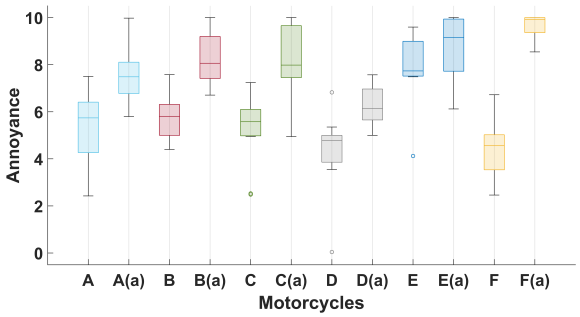

Figure 3: Boxplots of the annoyance ratings for motorcycles in idle and accelerated states.

Tonal Components

The tonal components and the frequency range, in which tonal components appear, can affect the annoyance response. Figure 4 depicts an example of the tonal components in idle and accelerated states. It can be seen that the tonal components do not appear in the idle state, however, there are several tonal components located densely in the frequency range between 100 to 500 Hz. This shows the dramatic change in the spectral behavior of one specific machine in different engine states.

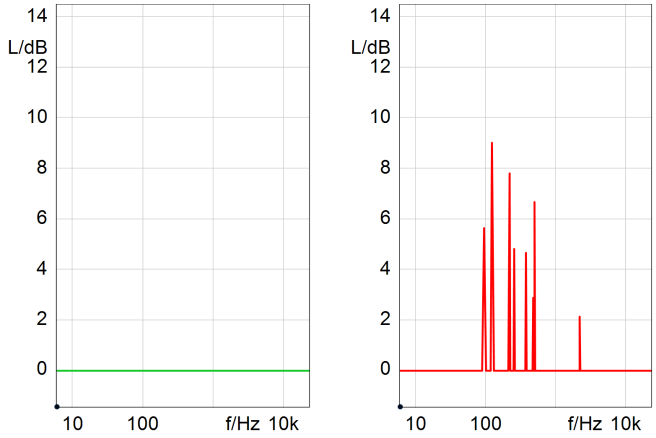

Figure 4: Comparison of tonal component distribution in idle state (left) and accelerated state (right).

Figure 5 shows the tonal component distribution of the most annoying motorcycle in the accelerated state based on the results of the listening test. The outcome shows a distinct tonal component at 120 Hz and a set of tonal components in the range of 500 to 2000 Hz. The spectral behaviors of the motorcycle in idle and accelerated states are completely different in this case as well.

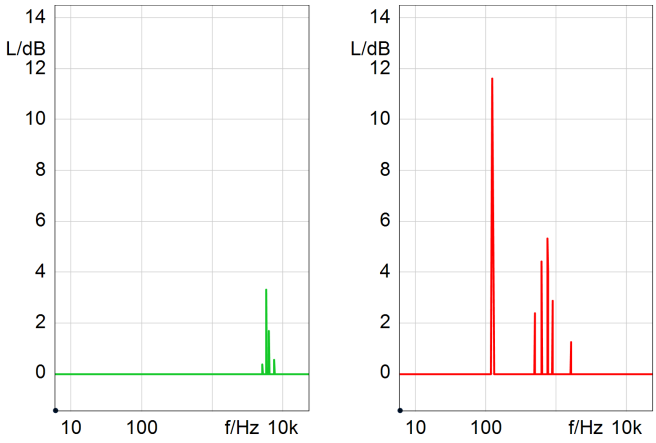

Figure 5: Tonal component distribution of the most annoying motorcycle in idle state (left), and accelerated state (right).

The spectrogram of the most annoying motorcycle in this study (motorcycle F) in Figure 6 clearly visualizes the presence of the tonal components in the emitted noise. The dominant tonal component at 120 Hz in the accelerated state is barely noticeable in the spectrogram in the idle state. As it can be derived from Figure 3, motorcycle F is the most annoying machine between all measured motorcycles in accelerated state, whereas it is the least annoying machine in the idle state. This proves the considerable change in the emission and spectral characteristics between two different engine modes.

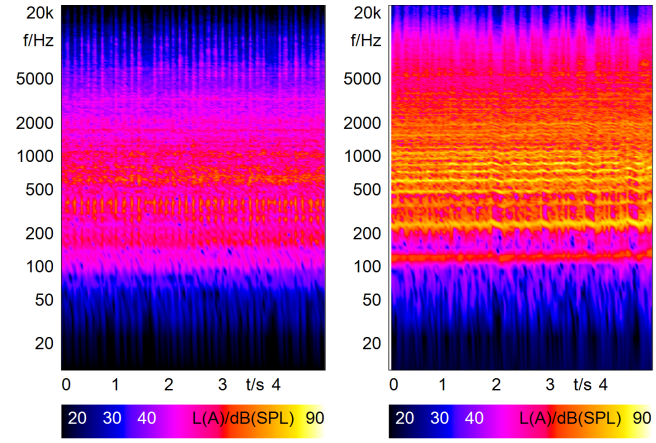

Figure 6: Spectrogram of the stimulus for the most annoying motorcycle in idle state (left), and accelerated state (right).

Figure 7 illustrates the distribution of the tonal components for the least annoying motorcycle. Interestingly, in this case no tonal component is noticeable. Among all studied motorcycles, the vehicle, which is perceived and rated as the least annoying motorcycle by participants, does not have any tonal component in the accelerated state as shown in Figure 7.

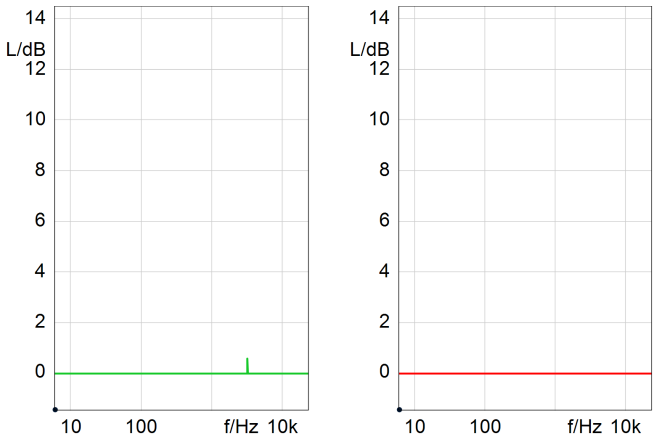

Figure 7: Tonal component distribution of the least annoying motorcycle in idle state (left), and accelerated state (right).

Distribution of Annoyance Responses

To compare annoyance responses of idle and accelerated states, the probability density estimates for each motorcycle in both states were plotted. The Kernel distribution is used to depict the proportion of responses for each annoyance value. The estimator reflects the statistical likelihood of a random variable and it was computed using Equation 1 [6].

$$f(x) = \frac{1}{nh} \sum_{i=1}^{n} K\left(\frac{x - x_i}{h}\right) \tag{1}$$

where n is the sample size, h is the bandwidth that is responsible for controlling the curve smoothness, K is a smoothing function that determines the shape and defines contentiousness of the plotted probability density curve, and x is the sample of a distribution.

Overall, the annoyance ratings of the motorcycles considered in this study in the accelerated mode are higher than in idle mode. Probability density estimates for the idle state are visualized in Figure 8 and the corresponding peaks lie in the annoyance interval from 4 to 8. In this state, the most annoying vehicle is motorcycle E with a distinct annoyance response peak located around 8.

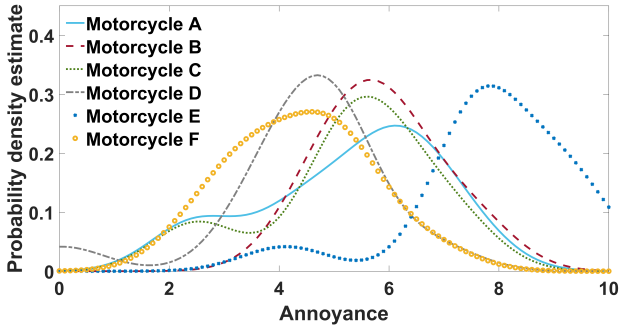

Figure 8: Probability density estimate of annoyance for idle state.

The total area under the probability density curve is equal to unity [7], and shows to which intervals the random variables fall. Figure 9 shows Kernel distributions for the accelerated state. Compared to the idle state, the majority of the plot peaks are shifted to the annoyance rating interval between 6 to 10.

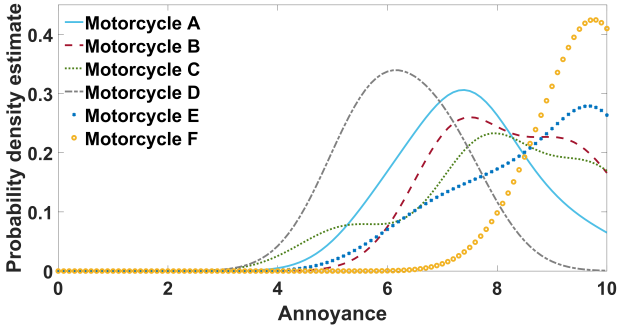

Figure 9: Probability density estimate of annoyance for accelerated state.

In contrast to motorcycles B, C and E that have larger spread of annoyance responses, motorcycles A, D and F have distinct peaks in the accelerated state. In the idle state, the annoyance ratings are accumulated in the interval from 4 to 6, however, in the accelerated state, this accumulation is shifted to the higher annoyance range. In addition, the annoyance ratings for accelerated and idle states do not coincide. The most annoying vehicle was revealed to be the motorcycle F in the primer case but, in contrast, the least annoying in the latter case. Although in the idle mode motorcycle E is the most annoying machine, in the accelerated state motorcycle F was chosen as the most annoying vehicle which has a very sharp annoyance response peak around 10. In this case, most of the ratings are accumulated in the interval between 8 and 10.

Correlation Between Annoyance and Psychoacoustic Parameters

The correlations between annoyance responses in both accelerated and idle states and the psychoacoustic parameters were computed using Pearson correlation method [8]. Equation 2 was used to calculate the correlation coefficient values.

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \overline{y})^2}} \tag{2}$$

where r_{xy} is the correlation value between the samples x_i and y_i, $\overline{x}$ and $\overline{y}$ are the sample mean values of x and y respectively, and n is the sample size.

The correlation could range between -1, which stands for the negative linear relationship, and 1, which shows positive correlation between datasets. Zero value stands for no correlation between evaluated datasets.

The estimated Pearson coefficient values are depicted in Figure 10. The interpretation of the coefficient was made

according to the classification of correlation strength [9] in a range from very weak to very strong. The annoyance responses in two engine modes were correlated with sound pressure level and psychoacoustic parameters, including loudness, sharpness, roughness and fluctuation strength. The correlations between annoyance and the first four parameters were found to have similar pattern for idle and accelerated conditions. However, the coefficient value between fluctuation strength and annoyance response is very weak for the idle state and strong for the accelerated state. The correlations between annoyance and roughness are in a range of very weak. According to the results, annoyance has the highest correlation with sharpness, loudness and sound pressure level.

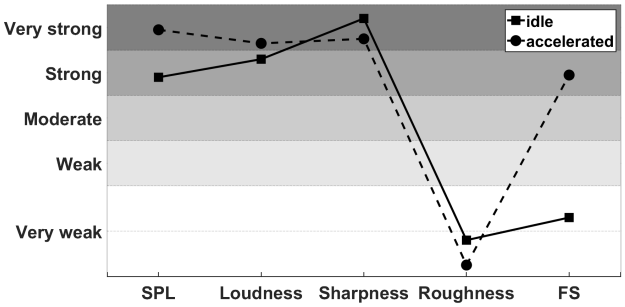

Figure 10: Correlation of annoyance with sound pressure level and psychoacoustic parameters.

Conclusion

The objective of this research was to investigate the effect of frequency content and tonal components of the noise emitted by motorcycles on the perceived annoyance, as well as to specify the correlation between the psychoacoustic parameters and the resulting annoyance.

From the outcome of our investigation it is possible to conclude that the spectral behavior varies considerably for various motorcycles and for different working conditions of the vehicle.

The presence of the tonal components in the emitted noise from the vehicle increased the perceived annoyance. Motorcycles with more distinct tonal components are prone to be perceived as more annoying, while vehicles with less or no tonal component are perceived as less annoying.

Based on the results of the listening tests and probability density estimates of annoyance ratings, all motorcycles are perceived as more annoying in the accelerated state.

The outcome of Pearson correlation analysis outlines that the correlation between the annoyance and psychoacoustic parameters in both idle and accelerated modes have similar patterns. In this case, annoyance has very weak correlation with roughness. The correlations between annoyance and fluctuation strength in idle and accelerated conditions are respectively very weak and strong.

The correlations of annoyance with loudness and sound pressure level in idle and accelerated states are respectively strong and very strong. Annoyance and sharpness are very strongly correlated in both idle and accelerated states.

Acknowledgment

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