DOI: 10.71568/daga2026.260



# Influence of Signal Duration on Subjective Dissonance Ratings

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## Introduction

Especially in recent years has the concept of dissonance been extended beyond musical contexts, in particular to the evaluation of technical sounds [1]. Whereas in classical music theory chords and intervals are typically categorized in a binary manner as either consonant or dissonant, psychoacoustic research on technical sounds indicates that dissonance is perceived as a continuous dimension [2]. Moving from a dichotomous classification of chords and intervals to a continuous perceptual sensation broadens the range of relevant influence factors: from isolated tones to varying harmonic configurations, the role of tonal context, and, importantly, the temporal evolution of sounds.

One way to investigate temporally varying sounds is an assessment of short excerpts of a longer sound to better understand their contribution to an overall assessment. The duration of the excerpts should be as short as possible to increase temporal accuracy while still being long enough to produce a stable percept and maximising the rated difference between consonant and dissonant sounds. Thus it is important to know how the dissonance sensation builds up over time.

A temporal build-up is well known for loudness perception. Loudness increases with signal duration, and sounds longer than approximately 250 ms can be expected to be rated equally loud as longer ones [3]. For dissonance, there are plausible reasons to assume a longer integration time, because dissonance is closely related to the perception of envelope fluctuations arising from the interaction of tones with slightly different frequencies [4]. These beating fluctuations can occur at very low modulation frequencies, so that short sounds would contain only a few beating periods. Furthermore, the perception of dissonance may involve higher-order auditory processing, which could require an increased processing or integration time.

Therefore, the present study investigates the influence of signal duration on subjective dissonance, rated on a categorical scale.

## Method

### Procedure

In a laboratory listening experiment subjects rated the dissonance of sounds with varying duration and different frequency intervals. Subjects were handed written instructions before the experiment, explaining the procedure. A particular emphasis was placed on ensuring that subjects understood that the presented sounds could be very short in duration. Before subjects rated sounds, they were presented with a detailed explanation of dissonance based on example sounds. Intervals sorted in order of increasing dissonance according to music theory were presented as piano sounds, but also as pure sinusoidal tones. Pink noise (as a non-tonal sound) and a combination of pink noise with intervals was also demonstrated. After the explanation, the rating-phase started. Subjects rated the dissonance of the sounds in random order on an equidistant 9-point scale, labeled from 0 to 8. Additionaly, Rohrmann labels 8 are added at 0, 2, 4, 6, ranging from 0 ("not at all") to 8 ("very") [5]. At the end of the psychoacoustic experiment, participants were briefly asked for their subjective impressions of the experiment using an open-ended question.

### Sounds

A total of 120 stationary sounds were presented in the listening experiment. Figure 1 shows the general sound composition. All sounds contained background noise with a decay of -6 dB per octave to higher frequencies and a sound pressure level of 24 dB at 500 Hz. All tones in the sounds also followed a -6 dB per octave slope with 46 dB sound pressure level at 500 Hz.

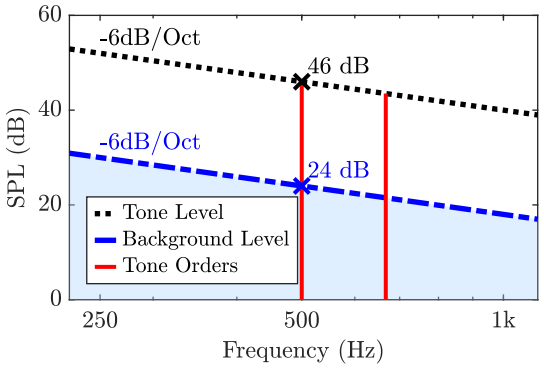


**Figure 1:** Visualization of the tone and noise composition scheme used for the sounds.

Table 1 shows the parameter variations in the sounds. Stimulus durations were logarithmically spaced, doubling at each step. The minimal duration was specifically chosen to be below the loudness build-up time of around 200 ms [3]. Due to the hypothesis, that dissonance perception might require longer to build up, the maximum duration was 2 s. Three interval configurations were selected based on their dissonance in music theory (see e.g.

[4]): no interval (minimal dissonance), a Fourth (low dissonance) and a Minor Second (maximal dissonance). The fundamental frequency is also varied in 4 steps. The logic behind the frequencies is that the Fourth with a fundamental at 400 Hz has the same frequency of the interval tone as the Minor Second with a fundamental at 504 Hz. The same applies for 900 and 1134 Hz. Lastly, every sound is presented either with or without two additional harmonics, to see whether the presence of additional orders affects the build up of dissonance perception. Both, fundamental frequency and harmonic variations, lead to a rich variety in sounds, minimizing the risk of subjects recognizing and categorizing the stimuli.

**Table 1:** Parameter Variations used in all Combinations

| Duration | Interval | Fund. Freq. | Harmonics |
|---|---|---|---|
| 0.125 s | w/o | 400 Hz | w/o |
| 0.25 s | Minor Sec. | 504 Hz | +2 |
| 0.5 s | Fourth | 900 Hz | |
| 1.0 s | | 1134 Hz | |
| 2 s | | | |

## Listening Setup

The listening experiment was carried out in a sound attenuated listening booth. The sounds were played from a computer running a Matlab-app connected to Sennheiser HD650 open headphones via a RME Fireface UFX III audio interface. The listening setup was calibrated using a GRAS 43AA-S2 CCP Ear Simulator and a 1 kHz sine with a defined level. All sounds were presented diotically with a 20 ms fade-in and fade out using half-Hann (raised-cosine) envelopes.

## Participants

Overall, 23 volunteers participated in the listening experiments. No subjects with self-reported hearing loss participated in the study. The Joint Ethics Committee of Bavarian Higher Education Institutions (GEHBa) had no objections regarding the study (GEHBa-202405-V-186).

## Results

Figure 2 shows the rated dissonance for the three interval configurations over signal duration. Ratings are averaged across different frequencies and harmonic components. The error bars show the standard error between subjects. For short durations of 125 ms, the average ratings of the three interval conditions are only around one category apart. Dissonance ratings increase strongly up to 0.5 seconds for the Fourth and the Minor Second and flatten out toward longer durations. For the condition with no interval tones, the ratings remain around the same value as expected.

Since the primary objective of this study is to assess how well subjects distinguish between intervals, the focus is on differences between interval ratings rather than their absolute values. The mean pairwise interval difference (MPID) was calculated for each duration $t$ as defined in Eq. 1. Specifically, the absolute differences of the ratings $R_i$ and $R_j$ for all possible pairs of the $n$ interval

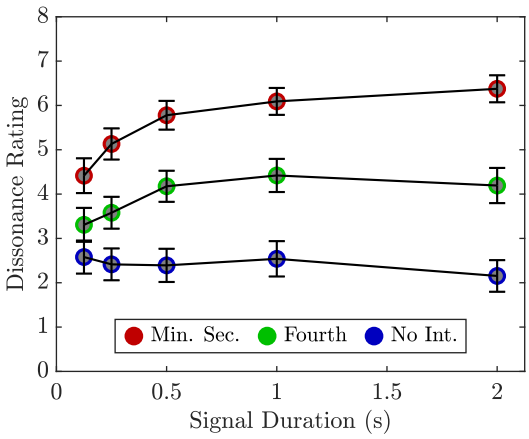


**Figure 2:** Dissonance ratings for the different intervals over duration, averaged across participants, harmonics and fundamental frequency variations.

conditions were computed, summed, and then divided by the total number of pairwise combinations. This measure reflects the separation in the ratings between all interval pairs averaged and thus provides a more direct indicator of discriminability. The following figures present the MPID instead of mean interval ratings, allowing for a clearer interpretation of interval differentiation across conditions. Error bars indicate the inter-subject standard error of the mean pairwise interval difference, thereby quantifying inter-individual variability across participants.

$$\mathrm{MPID}(t) = \frac{2}{n(n-1)} \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} |R_i(t) - R_j(t)| \quad (1)$$

Figure 3 shows the mean pairwise interval difference (MPID) for all participants, along with the group mean and corresponding standard error. Individual responses exhibit substantial variability across subjects. Large absolute values of MPID reflect stronger interval differentiation, but can also arise from differences in individual scale usage. Despite the inter-individual variability, the individual curves generally follow the trend of the group mean. For very short signal durations below 0.5 s, interval differentiation is low, increasing rapidly from 0.125 s to 0.5 s before approaching a more gradual increase at longer durations above 0.5 s.

Figure 4 shows the mean pairwise interval difference (MPID) with and without overtones in the sounds. The MPID is higher when the two additional harmonics are contained in the signal. The presence of overtones means that the interval occurs three times instead of once, causing three beating frequencies instead of one, in case of a dissonant interval, which could explain the increased difference in the ratings.

This interpretation is further supported by the results in Figure 5, which shows that the inclusion of harmonics also leads to a general increase in raw dissonance ratings

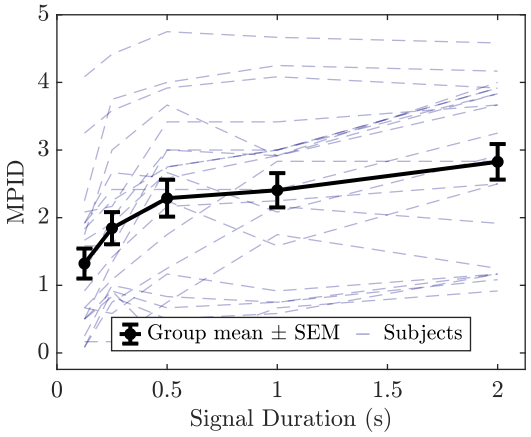


**Figure 3:** Mean pairwise interval difference (MPID), averaged over harmonics and fundamental frequency variations.

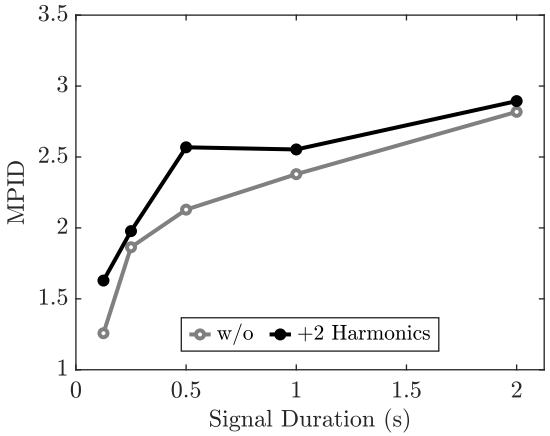


**Figure 4:** Mean pairwise interval difference, averaged over fundamental frequency variations.

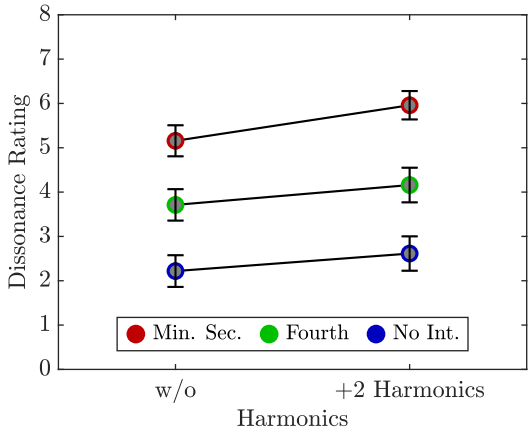


**Figure 5:** Dissonance ratings for the different intervals over harmonic conditions, averaged across participants, duration and fundamental frequency variations.

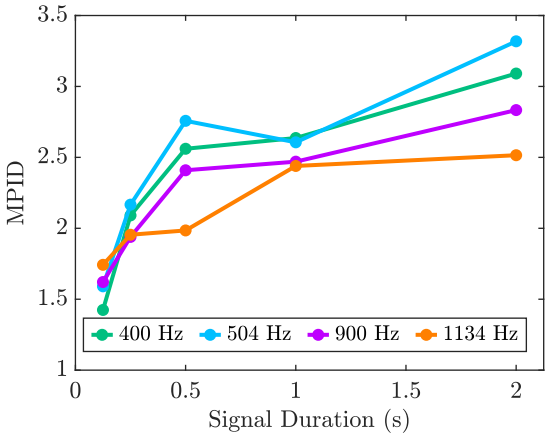


**Figure 6:** Mean pairwise interval difference, averaged over harmonics.

across the subject group. For Minor Second and Fourth, this effect could be explained in the same way, but the upward tendency in the ratings for the condition without interval tones hints towards a different effect. A possible explanation would be the increase in tonal content at higher frequencies with the harmonics, as previous studies have shown that intervals at higher frequencies can lead to an increase in rated dissonance [6].

Figure 6 presents the MPID for the different fundamental frequencies. For long signal durations, the MPID is slightly lower for higher frequencies. This effect can possibly be explained by the loudness differences of the tones. With regards to the 6dB/octave level decay toward higher frequencies and the equal-loudness contours, the fundamental frequencies at 400 Hz and 504 Hz have a loudness of 1.25 sone, respectively 1.24 sone, while the 900 Hz tone is at 1.07 sone and the 1134 Hz tone at 0.87 sone. However, the results at 0.125 s show a different trend. The MPID values are higher for higher frequencies, whereas for longer durations an opposite tendency can be observed with the lower frequencies having higher MPID than higher frequencies.

As a response to the open question at the end of the experiment, many participants indicated that especially the shorter sounds were difficult to assess in terms of dissonance.

## Discussion

In summary, increasing signal duration leads to a progressively larger separation of the ratings assigned to different frequency intervals. Although the general shape of the build-up curve resembles the asymptotic behavior known from loudness perception [3], the underlying time constants differ. Whereas loudness reaches a near-final value within about 200 ms, the interval differentiation observed in the present results only exhibits a reduced growth rate after approximately 0.5 s.

From a methodological perspective, the results suggest that a signal duration of about 1 s is sufficient to obtain dissonance ratings with maximal distinguishability in listening experiments with a rating scale. Note that another experimental method, e.g. alternative forced choice (AFC) could result in slightly different effects of stimulus duration on perceptual judgments [7].

For the shortest duration of 0.125 s, the results show a

trend towards a larger MPID in the ratings for higher frequencies. This finding could support the hypothesis that a minimum number of envelope fluctuations must be perceived in order for dissonance to emerge.

A further interesting aspect is the tendency of increased interval differentiation between signal durations of 1 and 2 seconds. This effect may reflect the onset of cognitive processing mechanisms, which are known to influence temporal perception in this time range [8].

Taken together, these findings highlight the importance of signal duration when assessing dissonance, which may influence ratings of temporally varying tonal sounds. The observed relationship between interval differentiation and signal duration indicates that dissonance perception cannot be fully captured by short-time analyses alone, but requires a minimum temporal context to stabilize. The results suggest, that subjective dissonance ratings include an integration process over time rather than an instantaneous evaluation of spectral relations. Consequently, signal duration should be taken into account as an important parameter when designing experiments or models aimed at capturing perceptual attributes of dissonance in non-stationary sounds.

## Acknowledgements

The authors acknowledge the financial support for the research project *AudioOpt* by the German Federal Ministry of Research, Technology and Space as part of the funding program *VIP+* (contract number 03VP11931). The authors would also like to thank the industrial partners in the associated committee.

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