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Psychoacoustics of a chilling sound

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We digitally synthesized versions of the sound of a sharp object scraping across a slate surface (which mimics the sound of fingernails scraping across a blackboard) to determine whether spectral content or amplitude contour contributed to its obnoxious quality. Using magnitude estimation, listeners rated each synthesized sound's unpleasantness. Contrary to intuition, removal of low, but not of high, frequencies lessened the sound's unpleasantness. Manipulations of the signal amplitude had no significant impact on listeners' unpleasantness estimates. Evidently, low-frequency spectral factors contribute primarily to the discomfort associated with this sound.

Most people cringe when fingernails are scraped across a chalkboard; for some individuals simply imagining this aversive event evokes a wince. Rare (and perverse) is the person who smiles while sending shivers down the spines of others by scratching a hard surface. So ubiquitous is the reflexive reaction to these kinds of scraping sounds that modern lexicographers have recommended resurrecting the archaic verb *gride*, which describes this merciless act (Bowler, 1982). Even Aristotle (ca. 335 BC, cited in Loveday & Forster, 1984) acknowledged the aversive quality of these kinds of sounds, dubbing them "hard sounds."

Despite the almost universal reaction to such sounds, surprisingly little is actually known about the phenomenon. It is commonly believed that high frequencies are responsible for the unpleasant quality of this and similar kinds of grating sounds (Boyd, 1959; Ely, 1975), but to the best of our knowledge this belief has never been substantiated. Accordingly, we performed a series of experiments to determine the acoustic properties responsible for signaling this kind of aversive event. Contrary to popular opinion as well as our initial expectations, high frequencies were found to contribute little to judged unpleasantness of this chilling auditory stimulus.

EXPERIMENT 1

In the first experiment, we searched for a version of a "griding" sound that mimicked fingernails scraping across a chalkboard and, hence, was uniformly rated as unpleasant by a sample of listeners. We obtained judgments of pleasantness/unpleasantness for a number of different sounds, all presented at equivalent sound levels.

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Method

A sequence of 16 different stimuli was tape-recorded for this preliminary study. The sounds were selected such that, to the authors, half seemed unpleasant and the other half sounded pleasant or neutral. Recordings were made using a Teac A-3300S reel-to-reel tape recorder and an AKG Acoustics CK 4 microphone. The frequency response curves of the microphone and tape recorder were flat (± 2 dB) up to 20.0 kHz. Stimuli were matched in duration (approximately 3 sec) and in amplitude by matching the largest excursions on a VU meter during the recording procedure. The signals were amplified using an NAD integrated amplifier (Model 3020B) and delivered over Yamaha Orthodynamic headphones (Model YH-1). The frequency response of the headphones was reasonably flat, rising 6 dB to a peak at 3.0 kHz and falling 6 dB to a trough at 8.0 kHz. Twenty-four adult listeners rated the pleasantness of each sound by placing a mark somewhere along a 15-cm line labeled *pleasant* at one end and *unpleasant* at the other.

Results and Discussion

The results are shown in Table 1, which lists the various sounds, the average rating assigned to each, and the associated standard error. The ratings represent the distance, in centimeters, from the end of the line labeled *pleasant* to the position of the mark entered by the listener. Thus, signals judged to be more pleasant have lower ratings and those deemed to be more unpleasant have higher ratings. The sounds presented in Table 1 have been listed in order from least to most unpleasant. There was little disagreement regarding which sounds were most unpleasant, as evidenced by the low standard errors associated with the sounds that received the highest unpleasantness ratings. Not surprisingly, the stimulus reliably judged to be the most unpleasant was that produced by slowly scraping a three-pronged garden tool (True Value Pacemaker model) over a slate surface; this stimulus was also disturbingly similar to the sound of fingernails scratching across a chalkboard.

Having selected a particularly aversive version of this type of sound, we next sought to determine how much we could alter its acoustic properties without affecting its unpleasantness. We generated a digital version of this sound so that we could manipulate its spectral and temporal composition, as well as characterize it using Fourier analysis. The sound was digitized by passing the 3-sec recording through the analog-to-digital converter of

Table 1
List of 16 Sounds Used in Experiment 1, and the Average Rating (Expressed as Position in Centimeters Along the Line) and Standard Error Assigned to Each

Sound	Average Rating (cm)	SE
1. Chimes	4.72	0.57
2. Rotating bicycle tire	5.49	0.50
3. Running water	5.89	0.55
4. Jingling keys	6.25	0.67
5. Pure tone	8.79	0.62
6. Pencil sharpener	8.81	0.54
7. Shaking metal parts	8.89	0.53
8. White noise	9.09	0.57
9. Compressed air	9.58	0.58
10. Blender motor	10.90	0.46
11. Dragged stool	11.43	0.43
12. Metal drawer being opened	12.12	0.43
13. Scraping wood	13.03	0.38
14. Scraping metal	13.08	0.39
15. Rubbing two pieces of styrofoam together	13.39	0.38
16. Scraping slate	13.74	0.18

Note—The descriptor "scraping" refers to dragging the three-pronged garden tool across the designated surface.

a PDP-11/34 computer; the sampling frequency was 20.0 kHz. Playing back the digitized record at a 20.0-kHz output rate necessitated lowpass filtering of the signal at 8.0 kHz. To the authors and several other reluctant volunteer listeners, the digitized, filtered signal sounded very similar to, and just as unpleasant as the original.

The upper portion of Figure 1 shows the distribution of acoustic energy comprising this digitized sound over time. This spectrogram illustrates that this particular sound consists of several prominent harmonics, the lowest at 2.8 kHz. In addition, the unpleasant sound has an aperiodic temporal structure with a rapidly fluctuating amplitude envelope, as shown in the bottom portion of Figure 1. The following experiments were performed to determine if either of these properties, spectral content or temporal fine structure, contributed to the sound's obnoxious quality.

EXPERIMENT 2

To evaluate the contribution of spectral content to the sound's unpleasant character, we removed energy from different frequency regions and asked listeners to estimate the unpleasantness of these various filtered signals.

Method

The digitized signal was either highpass or lowpass filtered using a Krohn-Hite filter (Model 3343, two channels, 48 dB/octave each). Six lowpass and five highpass filter conditions were selected. The lowpass filter settings ranged from 8.0 to 3.0 kHz, and the highpass settings varied from 2.0 to 6.0 kHz, all in 1.0-kHz intervals. The signals were equated for power (RMS voltage) at all filter settings. Using magnitude estimation (Stevens, 1962), 12 listeners rated the unpleasantness of these stimuli by assigning to each sound

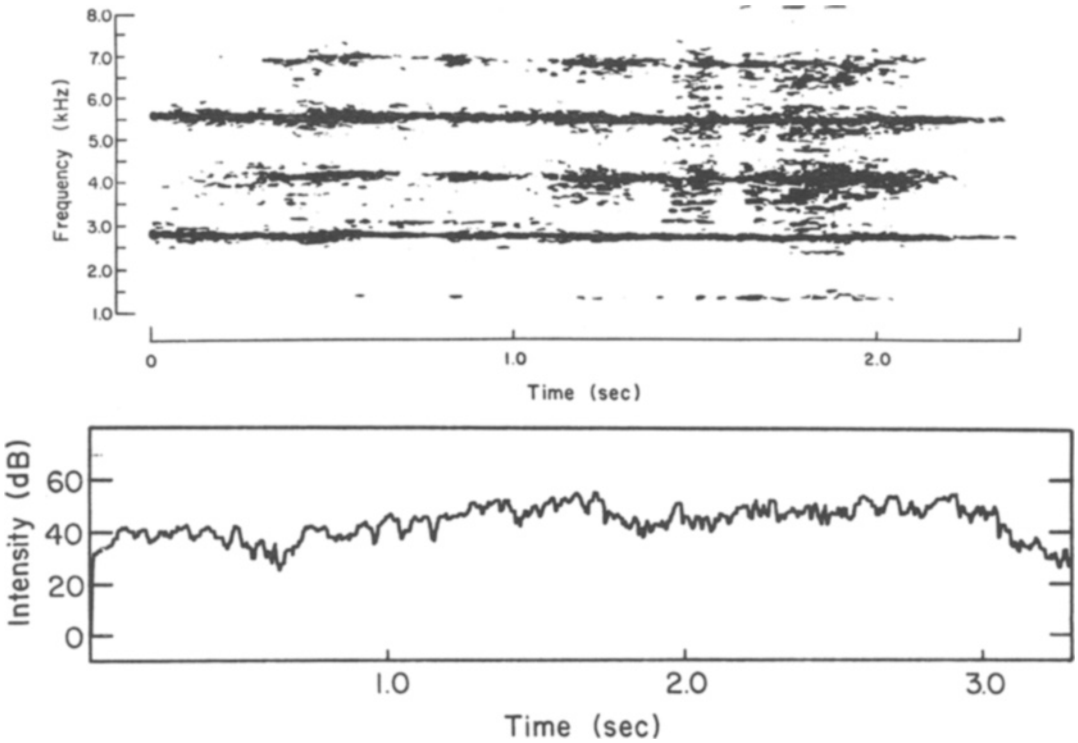

Figure 1. Spectrogram (upper panel) and amplitude waveform (lower panel) of the scraped-blackboard signal. The spectrogram shows the frequency content of the stimulus as a function of time. The amplitude waveform describes variations in the intensity of the signal over time. Note that the abscissa (time) is scaled differently in the two panels.

a number in proportion to its perceived unpleasantness. The 11 filtered signals were presented three times each in random order, and magnitude estimation judgments were obtained immediately following each 3.3-sec presentation. In this and all subsequent experiments, the subjects were told how the stimuli were created before they listened to them. There is some evidence to suggest that subjects react more strongly to this type of stimulus when they know in advance that they will be hearing it.[1]

Results and Discussion

The log magnitude estimates were averaged over the three presentations, and the data from all subjects were normalized according to established methods (Kling & Riggs, 1971; Lane, Catania, & Stevens, 1961). As summarized in Figure 2, decreasing the lowpass filter cutoff from 8.0 to 3.0 kHz had no effect on the unpleasantness ratings of the sound. The 2.0-kHz highpass version of the signal was judged to be as unpleasant as any of the lowpass filtered signals. As the highpass filter cutoff was increased further, however, the sound lost some of its unpleasant quality, even though all stimuli along the continuum were equal in overall intensity. Contrary to our initial expectations, then, high frequencies were apparently unnecessary for this uncomfortable auditory experience.

EXPERIMENT 3

Although the stimuli used in Experiment 2 were matched for RMS voltage, we had no assurance that they were perceived as equally loud. We were concerned, therefore, that the results in Figure 2 might be attributable to variations in perceived loudness of these equal-amplitude signals. To test the possibility that unpleasantness had been confounded with loudness, we presented subjects with selected stimuli from Experiment 2 and obtained their estimates of the loudness of these signals. If the data of Figure 2 actually represent differences in perceived loudness across stimulus conditions, then one would predict that the signals presented in this experiment would receive different estimates of loudness. One could argue that it would have been preferable to match the signals for loudness for each subject at the outset of the study. This, however, would have entailed multiple exposures of the signals to each subject. From repeated listening to these sounds, the authors came to believe that the sounds lost some of their unpleasantness with time. To prevent our subjects from adapting to the sound, we decided not to have each subject match the loudness of the signals before estimating their unpleasantness.

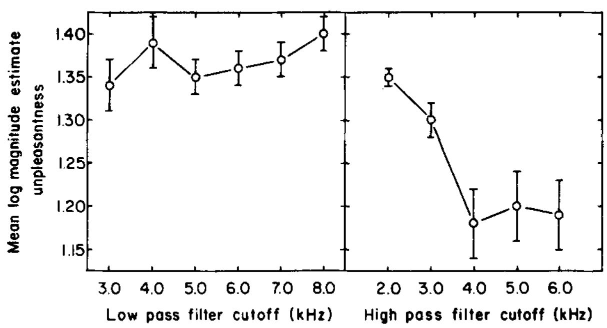

Figure 2. Mean log magnitude estimates of unpleasantness as a function of filter cutoff frequency. Lowpass filtering has essentially no effect on judged unpleasantness. Highpass filtering above 2.0 kHz decreases rated unpleasantness. Error bars indicate plus or minus the standard error for each mean.

Method

A different group of 12 subjects was asked to estimate the loudness of a subset of the original noises. To be certain that the subjects could indeed judge differences in loudness, we required them to give loudness ratings to each signal presented at two sound pressure levels (SPL), differing by 10 dB. The subjects listened to three lowpass filtered signals (cutoff values of 3.0, 5.0, or 8.0 kHz) and three highpass filtered signals (2.0, 4.0, or 6.0 kHz).

Results and Discussion

All data were normalized in the same fashion as those from the previous experiment. In both the lowpass and highpass filter conditions, estimates of loudness dropped by anywhere from 41% to 50% when the intensity of the signals decreased by 10 dB, confirming that the subjects were performing the magnitude estimation task properly. At a fixed SPL, there was essentially no difference in the estimated loudness of any of the lowpass and highpass filtered signals; judged loudness varied by no more than 10%. We are confident, therefore, that loudness differences were not responsible for the variations in unpleasantness with highpass filtering or for the invariance in unpleasantness with lowpass filtering.

EXPERIMENT 4

To evaluate the contribution of temporal fine structure, we needed to measure how removal of the fluctuations in the amplitude envelope of the signal influenced estimates of its unpleasantness. We were also interested in learning whether we could render a sound either more or less unpleasant by manipulating its amplitude contour.

Method

Four stimuli were used in this study, with these four differing in temporal fine structure and/or frequency content.

To create a version of the original stimulus that contained *no* variations in amplitude over time, the amplitude contour of the original signal (i.e., the waveform pictured in the bottom portion of Figure 1) was extracted. This temporal waveform was then inverted, and the original signal was multiplied by this inverted temporal waveform to cancel its amplitude fluctuations; the resulting stimulus will be referred to as the "demodulated original."

A complex stimulus was digitally constructed by summing together sinusoids corresponding to the first three prominent harmonics depicted in the Fourier transform of the original digitized signal. The phase and amplitude characteristics of the three-tone complex were matched to those of the original stimulus. One version of this signal had a flat amplitude envelope ("three-tone flat"). The other had the same temporal fluctuations as the original, achieved by multiplying the synthetic three-tone complex by the amplitude waveform extracted from the original signal ("three-tone modulated"). Twelve subjects were asked to estimate the unpleasant-

Table 2
Mean Log Magnitude Estimates and Standard Errors of the Unpleasantness of the Sounds Used in Experiment 4

Signals	Mean Log Magnitude Estimate	Standard Error
Original Amplitude Modulated	1.25	.04
Original Flat Amplitude	1.29	.05
Three-Tone Flat Amplitude	1.02	.06
Three-tone Amplitude Modulated	1.09	.03

ness of the four signals, that is, the original sound, the demodulated original, the flat-amplitude three-tone complex, and the amplitude-modulated three-tone complex. The order of signal presentation was randomized, and each sound was presented three times.

Results and Discussion

Normalized data from this experiment are summarized in Table 2. Inspection of the differences in the magnitude of the estimates suggested that the original and demodulated original sounds were judged to be more unpleasant than either of the three-tone signals; this was confirmed using the sign-rank test of differences ($p = .02$).

A randomized block analysis of variance revealed a significant difference among treatments [$F(3,33) = 5.68$, $p < .01$]. A Newman-Keuls comparison among treatment means indicated that unpleasantness estimates for the original signal were significantly different from those for the three-tone modulated stimulus, and that ratings for the original demodulated signal were significantly different from those for the three-tone flat-amplitude signal. No differences were found in comparing judgments for the original and original demodulated sounds or the three-tone flat and three-tone modulated stimuli.

These analyses suggest that the frequency content of these signals contributes more to judged unpleasantness than does the amplitude contour. For the authors, the three-tone complex captured only part of the unpleasant quality of the original sound. It may be that lower amplitude frequency elements present in the original signal, but not synthesized in the three-tone complex, provide a richness to the sound which contributes to its unpleasant character. The manner in which spectral content does contribute to the unpleasant quality of a sound cannot, however, be studied simply by highpass or lowpass filtering of the signal.

GENERAL DISCUSSION

Our results demonstrate that the unpleasant quality associated with the sound of a solid object scraped across a chalkboard is signaled by acoustic energy in the middle range of frequencies audible to humans. High frequencies, contrary to intuition, are neither necessary nor sufficient to elicit this unpleasant sensation. Still unanswered, however, is the question of *why* this and related sounds are so grating to the ear. The automatic, almost visceral reaction to this sound makes us wonder whether it mimics some naturally occurring, innately aversive event. For example, the complex acoustic stimulus pictured in Figure 1 very closely resembles some of the spectrograms of warning cries emitted by macaque monkeys (Green, 1975). As another possibility, the signal may be similar to the vocalizations of some predator. Regardless of this auditory event's original functional significance, the human brain obviously still registers a strong vestigial response to this chilling sound.

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NOTE

1. Ely (1975) measured palmar skin potential responses to both blackboard screeches and pure tones. He found that when subjects had prior knowledge of what the sound was, skin potentials increased in response to the blackboard screeches; skin potentials of uninformed listeners were not elevated by as much. These results suggest that prior knowledge sensitizes listeners to the unpleasant sound. Therefore, the instruction set used in this study included a description of the three-pronged garden tool being dragged across a slate surface. Virtually all subjects shuddered upon reading this portion of the instructions.

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