edge and learning arising from intensive protocol analyses of students learning. Creating these materials will be the continuing stimulus for many books on this topic to come.

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Profile Analysis: Auditory Intensity Discrimination

David M. Green. New York: Oxford University Press, 1988. 138 pp. Cloth, $35.00.

A persistent complaint about psychoacoustics is that investigators have beat to death the study of 1000-Hz tones. One wonders: "When are they going to do something that relates to the real world, such as auditory processes that might be involved in speech perception?" Perhaps this is why David Green has captured the interest of researchers in psychoacoustics with his recent experiments on profile analysis. In the standard signal-detection task on intensity discrimination, the observer compares two signals that differ in overall intensity and states which is the loudest. In profile analysis, the stimulus consists of many tonal components; one of the components is treated as the signal and the other components as the masker. The signal component differs slightly in intensity, whereas the intensity of the masker components remains fixed. The task of the observer is to indicate which interval contains the signal component with slightly greater intensity. Contrary to tradition, the stimulus in profile analysis is complex rather than simple. Observers are still well practiced, but now there is a reason for requiring practice. The complex signals must be learned or, at least, the observer has to learn how to listen to them in the task. Green reports that some observers find it extremely difficult to do the task, and they still perform rather poorly after a few hours of training. These poor listeners are not tested further, eliminating some unknown subset of the putative population being studied. Finally, in many experimental conditions, the stimulus uncertainty is great because several properties of the stimulus are varied randomly from trial to trial.

It is important to realize just how much this eminent psychoacoustician has broken with tradition (much of which he contributed) by engaging in this research enterprise. Psychoacoustic research has usually followed an implicit, if not explicit, agenda: Simple stimuli, highly practiced observers, and tasks with low stimulus uncertainty are necessary for good psychoacoustic experiments. Although not the first heretic from within the psychoacoustic fold, Green rejects these standards in his paradigm of profile analysis. Louis Braida and Nat Durlach and Charles Watson and colleagues stand out as intellectual ancestors. In fact, Green's research began in collaboration with Murray Spiegal, who had worked in Watson's laboratory while a doctoral student.

To set the stage for Green's research, a review of Watson's paradigm seems worthwhile—although Green does not provide any review in his book. Watson's goal was to study processing of acoustic signals having speechlike properties (Watson, Kelly, & Wroton, 1976). The property of speech evidently most apparent to Watson was the sequencing of segments or phonemes. A sequence of 10 short tones was used as the test stimulus analogous to speech. A typical task involved same-different judgments of two sequences differing in a single tonal component. Some interesting results came out of this work. First, as in earlier studies of auditory backward recognition masking, the silent interval after the tonal component was important. Decreasing the silent interval after a tone reduced the tone's discriminability. Also, tones later in the sequence were easier to perceive than tones earlier in the sequence. High tones were perceived more easily than low tones. Finally, with sufficient practice and stimulus certainty, listeners were able to "hear out" a single tone. If the other nine tones were held constant from trial to trial and if the two sequences could differ only on the ninth tone, subjects were remarkably good at discriminating a difference relative to the case in which any tonal component could differ or the background tones could vary from trial to trial. Green and Spiegal's modification was to eliminate the sequential dimension of Watson's task and to present all of the tones simultaneously.

A new paradigm is not sufficient basis for excitement; what is needed is an unintuitive result or two. A cardinal rule of psychoacoustics, and perhaps psychophysics more generally, is that one signal interferes with the processing of another. A second tone interferes with the detection of a test tone (when the masker tone falls within the critical band of the test tone). In profile analysis, adding additional tones (outside the critical band) significantly helps detection (or discrimination) of the test tone. In intensity discrimination, a tonal signal is presented at one amplitude in one interval and at another amplitude in the other interval. The dependent variable is the threshold value of the increment relative to the standard in decibels (dB). Subjects can discriminate about a 5-dB difference between two isolated tones. Adding 20 masker tones to the tonal signal in each interval disrupts performance, so that the listener cannot discriminate less than a 60-dB increment in the signal tone. Adding tones clearly makes the task more difficult. How do we make it easier? As mentioned previously, the added tones should fall outside the critical band of the signal. With this constraint, adding 20 tones improves performance dramatically, allowing the subject to discriminate just a 3-dB increment in the tonal signal tone. This result contrasts with the 60-dB increment required for discrimination when masker tones are added within the critical band.

The advantage of detecting signals with additional tonal tones well outside the critical band of the signal implies that listeners can relate information across widely different frequency ranges. This ability is also apparent in listeners' skill at perceiving a melody whose notes jump across different octaves, as long as the contour and chroma are preserved (Idson & Massaro, 1978). Of course, melody recognition requires the integration of successive tones, whereas profile analysis requires the recognition of simultaneous tones.

Analogous to the Watson studies, a factor of central interest is stimulus uncertainty. There is about an 8-dB advantage when the signal frequency is fixed across trials relative to being varied from trial to trial. There is a smaller advantage when the masker is fixed across trials relative to having trial-to-trial variation.

A central theme of Green's research is that profile analysis differs from intensity discrimination. Evidence for this difference is grounded in the differential influence of independent variables in profile-analysis and intensity-discrimination tasks. One variable is the interstimulus interval (ISI) separating the two stimuli on a given trial in the forced-choice task. In one study, this interval was varied between 0.25 s and 8 s. The dependent variable was the signal level of the increment that was necessary to achieve a given degree of accuracy. The results revealed a main effect of task and an interaction with ISI. Overall performance was better in the profile task, and increasing the ISI decreased performance accuracy in the intensity task, but not in the profile task. Phenomenologically, the listener has quite different experiences. In one case, the listener is remembering loudness and, in the other, sound quality.

Given these results and phenomenal reports, Green believes that the two types of stimuli are stored in memory in different manners. Memory for intensity discrimination is a memory for relative loudness, whereas memory for profile analysis is a memory for sound quality that is largely categorical. Green states that "discrimination of a change in the shape of spectra may involve quite different processes from those used to detect a change in level over time" (pp. 40–41). However, the lack of forgetting in the profile-analysis task should not be surprising. Early studies in this century found little or no forgetting with fixed standards and significant forgetting with roving standards. Harris (1952) observed that long-term memory for the test tone would increase with practice in the task and counteract any short-term forgetting with increases in the ISI. Failing to take into account the large body of research using roving, rather than fixed, standards in the psychophysical task, Green concludes that the storage of the sensation "is categorical" (p. 39).

Finding no forgetting across ISI is not reason to conclude that memory for the profile stimulus must be categorical. It is well known that silent intervals produce very little forgetting in memory for pitch, whereas significant forgetting is found if an interference stimulus is presented during the retention interval (Massaro, 1970). That is, a pure tone will interfere with same-different comparison performance in a tone-memory task, and the amount of interference will increase with increases in the duration of the interference tone. If the representation were categorical, then it should be immune to nonmeaningful stimuli occurring during the ISI. Because it does matter, memory for the profile must be continuous and susceptible to interference from sound. The signal frequency was fixed in the experimental studies that contrasted profile analysis and intensity discrimination. Perhaps varying the signal frequency from trial to trial would have more easily revealed some detrimental effect of increasing the ISI. Forgetting functions have been found for loudness, pitch, and vowel quality; however, I know of no study of memory for timbre. Generalizing from the studies that have been done, however, we can expect that forgetting will also occur for timbre when a roving standard is used.

Profile analysis is putatively a different ballgame compared with intensity discrimination. The apparent differences between these two domains parallel the types of differences found in other areas of psychological inquiry. For example, differences have been found in perceptual-identification and recognition-memory measures of a prior learning experience (Jacoby, 1983). Behaviorally, the two tasks appear to be differentially influenced by experimental variables. In memory research, this observed dissociation might be taken as support for two separate memory systems. Analogously, it might be argued that profile analysis engages a different perceptual system than that engaged by intensity discrimination. The important question, however, is whether the listener is simply using different properties of the test stimulus or whether different processes are actually being engaged. As in other domains, we are faced with whether information or information processing is the critical factor.

The question of different processes involved in intensity discrimination and profile analysis suggests a dual-task in which both types of processing would be required for good performance. The proposed experiment is to create stimuli that differ both in profile and overall intensity. These stimuli already exist in most profile experiments. In the present task, however, subjects will first learn two prototypes that differ in both overall intensity and in profile. The stimuli can be called A and B, blip and blap, or whatever two labels seem natural. In the proposed task, however, subjects will be asked to make a decision with respect to both intensity and profile. An increment in a component supposedly creates a qualitatively different sound. An increment in all of the components creates a more intense sound. A factorial design can be used to generate stimuli that differ in profile and intensity. Previous results can be used to determine the levels and range of each of the two dimensions. The question of interest is how the listener combines the two sources of information in the task and how different independent variables influence this process.

An important question is to what extent a listener can resolve one source in parallel with the other source. In speech and music, for example, we seem to process timbre and loudness simultaneously. The results can be analyzed to determine whether the two sources of information are processed independently of one another without crosstalk. Perhaps, to perform the task, a listener has to attend selectively to one source. The results can also be tested against this possibility. Previous results of training in the tasks suggest that listeners may have some difficulty in carrying out both tasks relative to just one. Performance in the dual-task can be compared to performance in a control condition in which subjects are asked to perform only one task ignoring variation along the other dimension.

Although Green is well aware of the contributions of context coding and sensory coding within the perspective of the Braida-Durlach model, he does not seem to view it as an explanation of his results. Rather, he discusses simultaneous and successive comparison. Intensity discrimination involves successive comparison, whereas profile analysis emphasizes simultaneous comparison. However, Green is simply describing the makeup of the stimuli and task, rather than the psychophysical and psychological processes at work.

The two-alternative forced-choice task appears to be used in this research out of tradition rather than necessity. In many experiments, the signal component remains fixed across a block of trials. In these studies, the listener is able to build up a long-term memory representation for the signal's quality. My bet is that this long-term memory component contributes more to performance than the short-term component available from the two presentations in the two-interval forced-choice task. Finding the same results in other tasks might be informative. For example, my argument would be that a single interval yes-no task with practiced observers would produce the same results as found in the two-interval forced-choice task. That is, subjects are building up a long-term memory for blip and blap. This memory is not categorical, in the same way that our memory for violins and clarinets cannot be categorical. At some level, the representation must be continuous auditory properties. Intensity discrimination, on the other hand, might be more dependent on the short-term component than the long-term component. This analysis is not all that different than what would be obtained from the Braida and Durlach (1972) perspective.

This proposed research might point to differences in the processing of pitch versus loudness or perhaps timbre versus loudness. Some psychophysical results addressing this issue must exist. One difference that comes to mind is the well-known time-order error in memory for loudness, but not for pitch (Koester, 1945). This result would also lead us to expect a more fragile memory for loudness than for pitch. Unfortunately, I know of no studies that have looked at memory for timbre in the manner that memory for pitch and loudness has been studied.

Evolution of audition as a communication system or even as a sensory system would favor the functional value of timbre rather than loudness. Overall loudness could not be a robust dimension of information because it varies so drastically with distance between the stimulus event and the sensing agent. Furthermore, the momentary listening conditions would have important consequences for perceived loudness. Thus, other dimensions of sound would have to carry the bulk of the information load. Pitch and timbre remain as properties of sound that could vary in an informative manner. Of course, duration, number, and sequencing of sound are informative for more complex messages, as in bird song and speech.

In summary, Green has initiated a set of research questions that should stimulate further research and contribute to our understanding of how sound functions as the best known medium of communication.

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