On the importance of considering the signal's frequency spectrum: Some comments on Macmillan's "Detection and recognition of increments and decrements in auditory intensity" experiment

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In a recent experiment on tonal masking, Macmillan (1971) reported that recognition of increments and decrements improves relative to detection performance as signal duration is increased. It is suggested that this result is largely artifactual, inasmuch as Macmillan's Os undoubtedly detected brief-duration signals by virtue of energy splatter produced by gating the signal on and off rectangularly. Since energy splatter produced by an increment is identical to that produced by a decrement, Os listening off frequency could not have possibly distinguished a brief increment from a decrement.

In a recent paper, Macmillan (1971) examined detectability and recognizability of sinusoidal signals added as increments and decrements to a continuous sinusoidal masker of the same frequency as the signal. Macmillan found that, for brief-duration signals, Os were unable to discriminate between just-detectable increments and decrements. As the duration of the signal was increased, however, recognition was found to improve markedly.

In a previous tonal masking study, Leshowitz and Wightman (1971) demonstrated that Os often base detection on signal energy present in spectral regions remote from the signal frequency, where signal energy is as much as 40 dB down from the on-frequency energy. The purpose of this note is to point out that, in the detection phase of the experiment reported by Macmillan, Os were also listening to off-frequency energy splatter. As a result, this data cannot be used to validate Macmillan's model of detection.

In order to interpret Macmillan's data in terms of simple energy-detection principles, it is necessary to describe the frequency content of the gated signal and the continuous masker. About 90% of the signal's energy is located in a narrow band, $2/(\text{signal duration})$ wide centered at the signal frequency. In view of the large dynamic range of the auditory system, the remaining 10% of the signal energy distributed as $(\sin x/x)^2$ outside this frequency interval cannot be ignored. This energy splatter

is produced by gating the signal on and off rectangularly. Specification of the energy distribution of the masker is complicated, since the masker is continuous. For the present purpose, we will assume that the "energy" spectrum of the masker is a line at the masker frequency.

Now we can describe the spectral representation of the increment (or decrement) employed in Macmillan's study. The energy spectrum of the increment is simply the difference between the energy spectrum of the signal-plus-masker waveform and that of the masker alone. Since the masker spectrum is assumed to be simply a spectral line at the masker frequency, the relative phase of the signal and masker cannot possibly affect the off-frequency energy distribution of the increment. Off-frequency energy does not vary with the phase difference between the signal and masker. Thus, given that an O is listening off frequency, increments would be indistinguishable from decrements.

On the signal frequency, quite a different situation exists. The energy of the increment (decrement) at the signal is sensitive to phase and is given by

$$\Delta E = SMT \cos(\theta_S - \theta_M) + S^2 T/2,$$

where $(\theta_S - \theta_M)$ is the relative phase of signal and masker, S and M are the amplitudes of the signal and masker, and T is the duration of the signal.

The description of the frequency content of the signal and masker in conjunction with a simple filter model

of the auditory detection process are now applied to the detection phase of Macmillan's experiment. To the extent that Macmillan's Os were listening in frequency regions off the frequency of the signal, increments and decrements would be equally detectable. Moreover, a test statistic based on the energy at the output of an auditory filter off the signal frequency could not possibly be used to distinguish between increments and decrements. Hence, although increments and decrements may be detectable, the O would not be able to say whether an increment or decrement had been presented. For brief-duration signals, Macmillan reported precisely these results.

Macmillan's own replication of Garner and Miller's (1944) failure to obtain temporal summation in a tone-in-tone masking experiment provides support for this off-frequency listening explanation of Macmillan's detection data. Leshowitz and Wightman (1971) have demonstrated that the absence of the customary trading relation between signal power and duration indicates that the auditory filter is tuned to a frequency region remote from the signal frequency. They showed that "removing" signal energy splatter by either filtering the signal or by adding a low-level wideband noise floor reinstates the typical intensity-duration trading relation.

Macmillan's findings that Os can discriminate increments from decrements when the duration of the signal is long can also be understood in terms of the filter model. According to Leshowitz and Wightman (1971), the location of the hypothetical auditory filter is changed in order to maximize the ratio of signal energy to masker energy at the output of the auditory filter. Since energy density at the frequency of the signal is proportional to signal duration, it is reasonable to suppose that as signal duration increases, the O moves his filter toward the signal frequency. Energy at the signal frequency is dependent on the relative phase of the signal and masker. Thus, the direction of energy change at the signal frequency now can serve as a reliable cue for discrimination of increments and decrements. We conclude, then, that for long-duration signals, the increase in recognition performance noted by Macmillan corresponds to a placement of the auditory filter in the vicinity of the signal frequency.

The implications of the analysis of Macmillan's data in terms of simple energy-detection principles are obvious. Unless the signal's spectrum is shaped with a filter having a near-rectangular narrow passband, Os

will be able to listen off frequency, and thus improve the signal-to-noise ratio. The location of this "best" listening region may not be defined either by the signal frequency or the masker frequency. Had Macmillan either filtered his signal, or employed a lower-level sinusoidal masker, or added a noise floor in his experiment, the

results (and presumably his conclusions) probably would have been substantially different.

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