Detection and intensity discrimination of a sinusoid with and without masker uncertainty

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BACKGROUND

- An extensive literature on the effects of uncertainty has shown that uncertainty regarding signal and/or masker parameters can limit sensitivity in detection and discrimination tasks, and that cueing can mitigate these effects. **The purpose of this study was to examine these effects and how they combine in the context of intensity discrimination[1], specifically at near-"threshold" stimulus levels.**
- In studies of near-threshold intensity discrimination, a common finding is that the level of the just detectable signal at "threshold," ΔA_{JND}, when added to a near-threshold pedestal or masker, A, is actually below absolute detection threshold, A_0.
- Because intensity discrimination can be conceptualized as a masked detection task (Miller, 1947) this finding has been termed "negative masking" (NM; Raab, Osman, & Rich, 1963) and begs the question, **"Why is discrimination better than detection?"** (Lasley & Cohn, 1981).
- The intrinsic uncertainty hypothesis of NM (e.g.,Tanner, 1961) suggests that intensity discrimination is better than detection because, in the discrimination task, uncertainty is minimized. The basic argument is that in the detection task, the observer possesses a "large initial uncertainty" (Green, 1961) about signal parameters and forms their decision based on the maximum output over some number of irrelevant channels. The presentation of a low-level pedestal provides an informative cue, which enables the observer to more effectively focus their attention on the channel of interest. Relative to detection, performance improves; thus, NM.
- Despite a long history of speculation, the intrinsic uncertainty hypothesis has received relatively little attention in studies of NM. Therefore, the primary aim of this study was simple: to investigate the effects of uncertainty in a NM paradigm as a first step in that direction. Specifically, we asked: **Does the introduction (or "reintroduction") of uncertainty in an intensity discrimination task influence the magnitude of NM that is obtained?**
- Furthermore, the intrinsic uncertainty hypothesis suggests that NM is the consequence of a multi-channel process. Alternative theories suggest a single-channel process (e.g., nonlinear transduction; c.f., Hanna, von Gierke, & Green, 1986). Thus, the involvement of multi-channel processes were also considered.

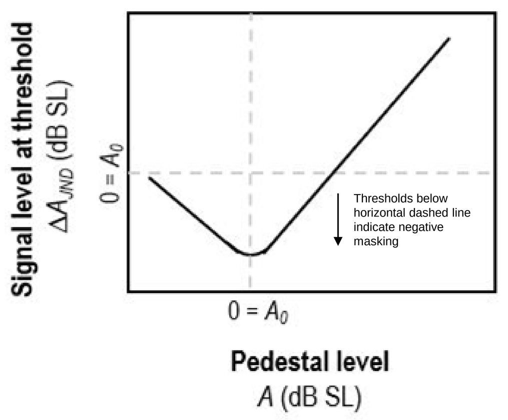
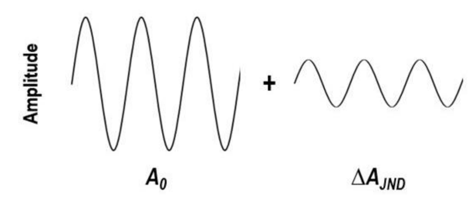


Figure 1. Above: Schematic of a typical masking function exhibiting negative masking. **Below:** Schematic of the amplitude of a 0 dB SL pedestal (left) and signal (right) at threshold assuming NM.



[1]Note that intensity discrimination is meant as a general term. All data presented here are expressed in terms of signal, ΔA, and pedestal, A, amplitude.

METHODS

Observers

- Three males, including the first author (Obs 2). Two completed both Experiment 1 and 2 (Obs 2 and 3 in both experiments).

Absolute detection thresholds

- In all conditions, the signal was a 100-ms, 1000 Hz sinusoid (5-ms cosine^2 onset-offset ramps)
- Between Experiment 1 and 2, thresholds were measured in three conditions: a quiet condition (quiet), a random-frequency, multicomponent masker condition (random), and a notched-noise condition (notched-noise). In Experiment 1, thresholds were only measured in quiet ($A_{0,\ Quiet}$). In Experiment 2, thresholds were measured in quiet and in masked conditions ($A_{0,\ Masked}$).

Intensity discrimination thresholds

- In all conditions, the signal was a 100-ms, 1000 Hz sinusoid added in-phase to a 100-ms, 1000 Hz pedestal (5-ms cosine^2 onset-offset ramps). In masked conditions, the signal, pedestal, and masker (also 100-ms, also gated with 5-ms cosine^2 ramps) were presented simultaneously.

Experiment 1

- Conditions: quiet, random
- Pedestals: -9, 0, and 9 dB re. $A_{0,Quiet}$
- In random condition, masker was a random-frequency, multicomponent complex consisting of four sinusoidal components. Each component was selected randomly on each presentation from a wide spectral range (80 – 8000 Hz), had a random phase (0 – 2π), and 3xERB protected region (roughly 398 Hz). The overall level of the masker was 30 dB SPL.

Experiment 2

- Conditions: quiet, random, notched-noise
- Pedestals: -9, 0, and 9 dB re. $A_{0,Quiet}$ and -9, 0, and 9 dB re. $A_{0,\ Masked}$
- The quiet and random conditions were the same as Experiment 1. The notched-noise (bandwidth 80 – 8000 Hz) had a 3xERB notch centered on the signal and was generated by summing individual sinusoids spaced 10 Hz apart [random amplitude (Rayleigh) and phase (0 – 2π)]. The overall level of the masker was 30 dB SPL.

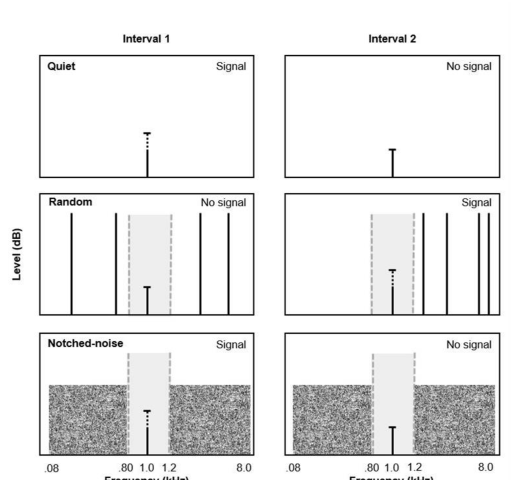


Figure 2. Schematic of the three total conditions tested during the intensity discrimination phase of Experiment 1 and 2. Absolute detection thresholds were measured under the same masked conditions but did not include a pedestal. Grey shading indicates the protected region in the masked conditions (same width all conditions).

EXPERIMENT 1

Results and Discussion

Absolute detection thresholds

- Absolute detection thresholds in quiet, $A_{0,\ Quiet}$, were 6 dB, -4 dB, and 9 dB SPL for Obs 1, 2, and 3 respectively. All pedestal and signal levels presented below are normalized to $A_{0,\ Quiet}$ for each observer.

Intensity discrimination thresholds, normalized to $A_{0,\ Quiet}$

Masker uncertainty eliminates negative masking

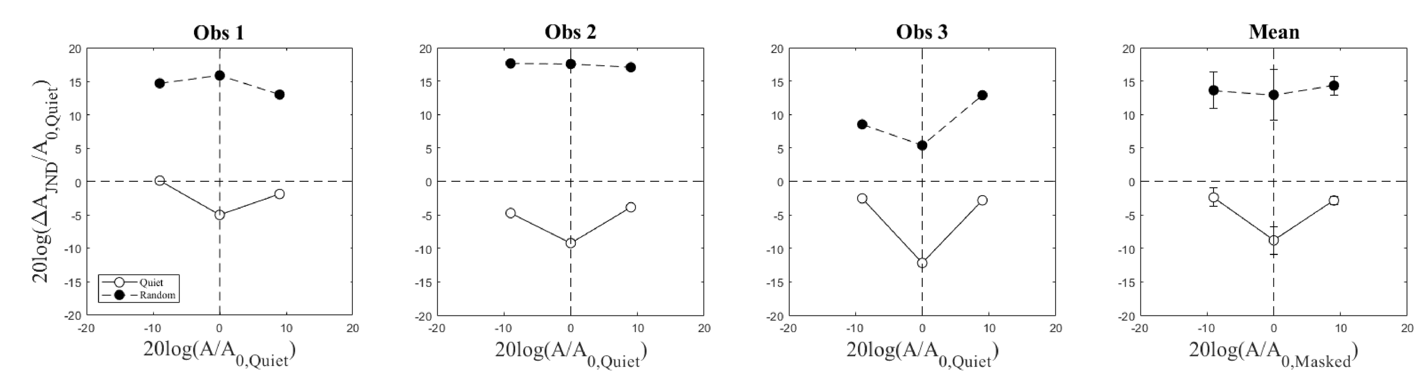


Figure 3. Masking functions measured in quiet (open symbols, solid lines) and in the random condition (black symbols, dashed lines). Error bars are standard errors of the mean. Note: Both the ordinate and the abscissa are normalized to each observer's absolute detection threshold in quiet, $A_{0,\ Quiet}$. **Points that fall below the horizontal dashed line indicate negative masking.**

- In quiet, NM was obtained for all three observers. The magnitude of NM yielded was consistent with past studies (e.g., Hanna, von Gierke, & Green, 1986; Viemeister & Bacon, 1988; Shepard & Hautus, 2009).
- However, in the random condition, NM was eliminated. For 0 dB SL pedestals, the point of maximum NM in quiet for all three observers, thresholds increased by between 18 and 26 dB.
- Results suggest that the introduction of masker-frequency uncertainty in an intensity discrimination task can eliminate NM.
- Results also suggest a role for multi-channel processes in NM.

Psychometric functions

Changes in slope are consistent with the effects of uncertainty

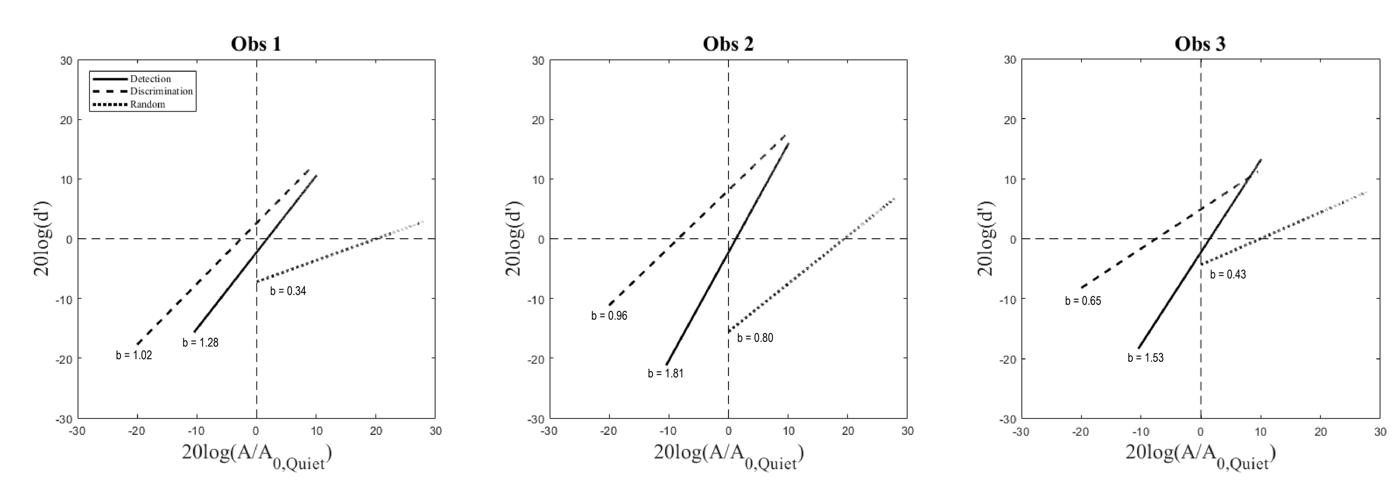


Figure 4. Psychometric functions for individual observers based on fits to data obtained during the adaptive tracking procedure. Psychometric functions are least-squares fits to the underlying data, representing the function $d' = a(\Delta A/A_0)^b$ (c.f., Green, 1988). The three lines in each panel represent three conditions: quiet detection (solid lines), intensity discrimination in quiet for 0 dB SL pedestals (dashed lines), and intensity discrimination in the random condition for 0 dB SL pedestals. Slopes (i.e., b) inset.

- Both the intrinsic uncertainty hypothesis and the nonlinear transducer hypothesis predict that the slope of the psychometric function will go from steep to shallow with the introduction of a pedestal.
- In quiet, psychometric functions for discrimination were shallower than those for detection, consistent with both hypotheses. However, in the random condition, psychometric functions were the shallowest, consistent with the effects of uncertainty (e.g., Oh & Lutfi, 1998; Durlach et al., 2005).

Informational or energetic masking?

- An alternative explanation for the elimination of negative masking in the random condition is that, despite the large protected region in the masker, the masker made a non-zero contribution to energetic masking of the signal and/or pedestal.
- Experiment 2 was designed to address this possibility.

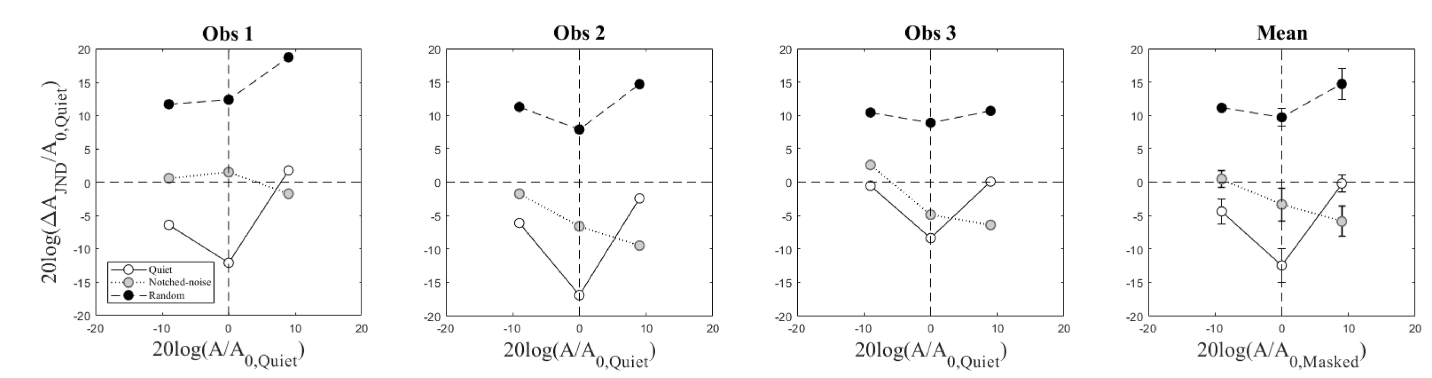
EXPERIMENT 2

Results and Discussion

Absolute detection thresholds

- Absolute detection thresholds in quiet, $A_{0,\ Quiet}$, were -2, 1, and 11 dB SPL for Obs 1, 2, and 3 respectively. Absolute detection thresholds in the presence of each type of masker, $A_{0,\ Masked}$, were and 1, 3, and 13 dB SPL in the notched-noise condition and 12, 13, and 16 dB SPL in the random condition for Obs 1, 2, and 3 respectively. All pedestal and signal levels presented below are normalized to either $A_{0,\ Quiet}$ or $A_{0,\ Masked}$ for each observer.

Intensity discrimination thresholds, normalized to $A_{0,\ Quiet}$



Intensity discrimination thresholds, normalized to $A_{0,\ Masked}$

Elimination of negative masking in random condition not due to energetic masking

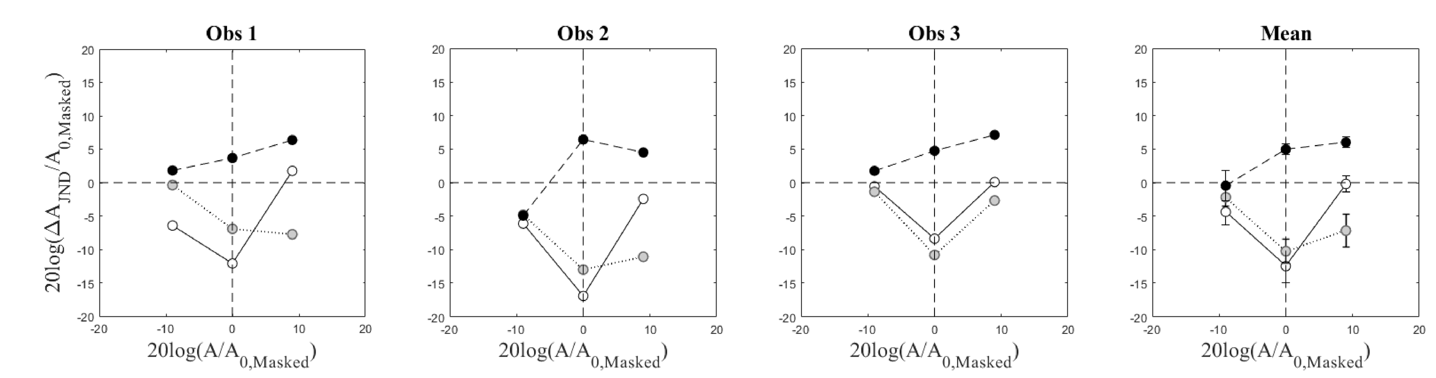


Figure 5. Masking functions for individual observers measured in quiet (open symbols, solid lines), in the random condition (black symbols, dashed lines), and in the notched-noise condition (gray symbols, dotted line). Error bars are standard errors of the mean. Note: In the top row, the ordinate and the abscissa are both normalized to each observer's absolute detection threshold in quiet, $A_{0,\ Quiet}$. In the bottom row, the ordinate and the abscissa are both normalized to each observer's absolute detection threshold in for the given masker, $A_{0,\ Masked}$. **Points that fall below the horizontal dashed line indicate negative masking.**

- When pedestals were normalized with respect to $A_{0,\ Quiet}$, NM was eliminated in the random condition and was reduced in the notched-noise condition (although note "crossing" of quiet and notched-noise masking functions for 9 dB SL pedestals, suggesting improvement via adoption of a profile analysis strategy; c.f., Green, 1988).
- When pedestals were normalized with respect to $A_{0,\ Masked}$, NM was still eliminated in the random condition save for a single point (Obs 2, -9 dB SL pedestal). Thresholds were similar in magnitude to quiet in the notched-noise condition.
- Results suggest a role for energetic masking in Experiment 1 but are consistent with the conclusion that the principle cause of the increase in thresholds in the random condition, and elimination of NM, was uncertainty.

SUMMARY

- Masker-frequency uncertainty can severely disrupt intensity discrimination for low-level pedestals, and can eliminate NM.
- Whereas the intrinsic uncertainty hypothesis suggests that NM reflects a release from uncertainty via cueing by the pedestal, our results work in the opposite direction and show that a "re-introduction" of uncertainty under informational masking can reverse or mitigate the beneficial effects of this cue and eliminate NM. Differences in psychometric function slopes across conditions in Experiment 1 also support the notion that a minimization of uncertainty is a prerequisite for obtaining NM.
- The elimination of NM under informational masking—despite a large protected region in the masker—suggests that NM involves multi-channel processes. Greater NM in notched-noise re. quiet for some pedestal levels (c.f., Figure 5) supports this conclusion.

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