

Masking and negative masking of low-level signals by low-level maskers under fixed and roved conditions

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BACKGROUND

- A peculiar finding in near-"threshold" psychophysics is that, under certain conditions, the detectability of a low-level, near-threshold signal may improve in the presence of a low-level, near-threshold masker—a finding termed "negative masking" (NM; Raab et al., 1963a). NM (also known as the "dipper" or "pedestal" effect; see **Figure 1**.) is a general phenomenon that occurs across sensory modalities (Solomon, 2009) and it is one that Green discusses in a handful of writings that span the entirety of his career (e.g., Green, 1960; Green, 1966; Green, 1988).
- Despite the fact that Green participated in only one empirical study explicitly concerned with NM (Hanna et al., 1986) his name looms large in the NM literature. That is because one interpretation of NM—known as the channel uncertainty hypothesis (CUH; Nachmias & Kocher, 1970)—is based on a theoretical interpretation of signal detectability that was originally proposed by Green (1961; see also Green, 1960; Tanner, 1961).
- In a seminal article, Green (1961) suggested that observers possess a large intrinsic uncertainty regarding signal parameters that limits detectability even when all signal parameters are fixed and "known" on each trial. The consequence of this uncertainty is the non-optimal processing of stimulus information across sensory channels or, more intuitively, a failure of selective attention along some physical dimension. Because the observer is unable to focus their attention on the single channel tuned to the signal, they instead monitor the output of some large number (M) of channels, only one of which is tuned to the signal. The Theory of Signal Detectability (Peterson et al., 1954) and related uncertainty models (e.g., Pelli, 1985) predict that, in a detection task, large M will degrade performance, yielding spuriously high estimates of threshold and a steep (i.e., nonlinear) psychometric function relative to the ideal. Both predictions are true of human observers, hence Green's suggestion of an intrinsic uncertainty.
- By implication, a reduction in uncertainty should result in "more nearly optimal" processing, a decrease in threshold, and a linearization of the psychometric function. That is, as M decreases from some large number, the performance of the human observer should approach the ideal. This is also true of human observers under conditions that yield NM (e.g., Hanna et al., 1986) and thus the CUH accepts Green's suggestion of an intrinsic uncertainty and argues that NM reflects its reduction, via simultaneous cueing by the masker.
- Despite a long history of speculation, the CUH remains somewhat controversial (e.g., Eskew et al., 1991) and in audition in particular suffers from a paucity of empirical data. **Thus, the primary aim of this study was simple: to investigate the relationship between uncertainty and NM.**
- In two experiments, uncertainty was introduced into a tone-on-tone masking task by roving either the signal or the masker along a single physical dimension. All other aspects of the stimulus situation were hypothesized to yield NM (e.g., Hanna et al., 1986; Viemeister & Bacon, 1988). The resilience or susceptibility of NM to this "reintroduction" of uncertainty was the main point of interest, as were changes in the psychometric function. It was hypothesized that if NM relies on a reduction of uncertainty relative to unmasked detection, as is suggested by the CUH, the rove would either minimize or even eliminate NM and provide qualitative support for the CUH.

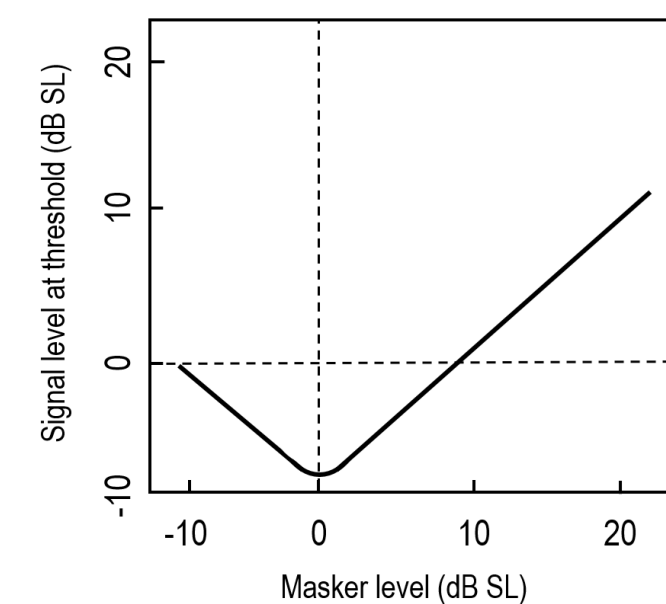


Figure 1a. Schematic of a typical "dipper" shaped masking function showing NM. The region of the "dip" indicates NM (cf., Solomon, 2009).

GENERAL METHODS

Observers

- Three males (including the first author, Obs 2), and one female participated (20 – 30 yrs., mean=23). Three observers were tested in each experiment. Two observers completed both experiments.

Procedures and conditions

- Both Experiment 1 and Experiment 2 consisted of two phases. The first phase was unmasked pure-tone detection. The second phase was tone-on-tone masking. In the second phase of both experiments, two conditions were tested: a fixed condition and a roved condition.
- In the fixed condition, all stimulus parameters were held fixed during a block of trials. In the roved condition, either the signal or the masker were randomly varied along a single physical dimension on a trial-by-trial basis.
- In all phases and conditions, a two-interval, two-alternative forced-choice adaptive tracking procedure was used to track the 70.7% point ("threshold" for all data shown here) of the underlying psychometric function.

Phase 1: Unmasked pure-tone detection

- In phase one of both experiments, "absolute detection threshold," A_0 , for the signal in isolation was obtained for each individual observer. These values were used to normalize the masker levels in phase 2 on a per-observer basis.

Stimuli: In Experiment 1, the signal was a 100-ms, 1000 Hz sinusoid with 5-ms cosine² onset-offset ramps. In Experiment 2 it was a 40-ms, 1000 Hz sinusoid, also with 5-ms cosine² onset-offset ramps.

Absolute detection thresholds: In Experiment 1, A_0 was 6, -4, and 9 dB SPL for Obs 1-3, respectively. In Experiment 2, A_0 ranged from 0 to 5 dB SPL.

Phase 2: Tone-on-tone masking under fixed and roved conditions

- Three masker levels bracketing/including each individual observer's absolute detection threshold were tested in both experiments and in all conditions. In Experiment 1, additional masker levels were tested in the roved condition.

Stimuli: In Experiment 1, the masker was a 100-ms, 1000 Hz sinusoid gated simultaneously with the signal. In Experiment 2, the masker was a 500-ms, 1000 Hz sinusoid gated with 5-ms cosine² onset-offset ramps. In Experiment 2, the signal onset relative to the masker onset was the parameter of interest.

EXPERIMENT 1

METHODS

Masker levels

- Fixed:** -9, 0, 9 dB re. each individual observer's A_0 (i.e., dB sensation level; SL)
- Roved:** -9, 0, 9, 27, 45, 81 dB SL

Rove

- "Discrete" rove of **masker level** (i.e., only six possible masker levels on each trial)
- Adaptive tracks interleaved so that thresholds for each masker level obtained

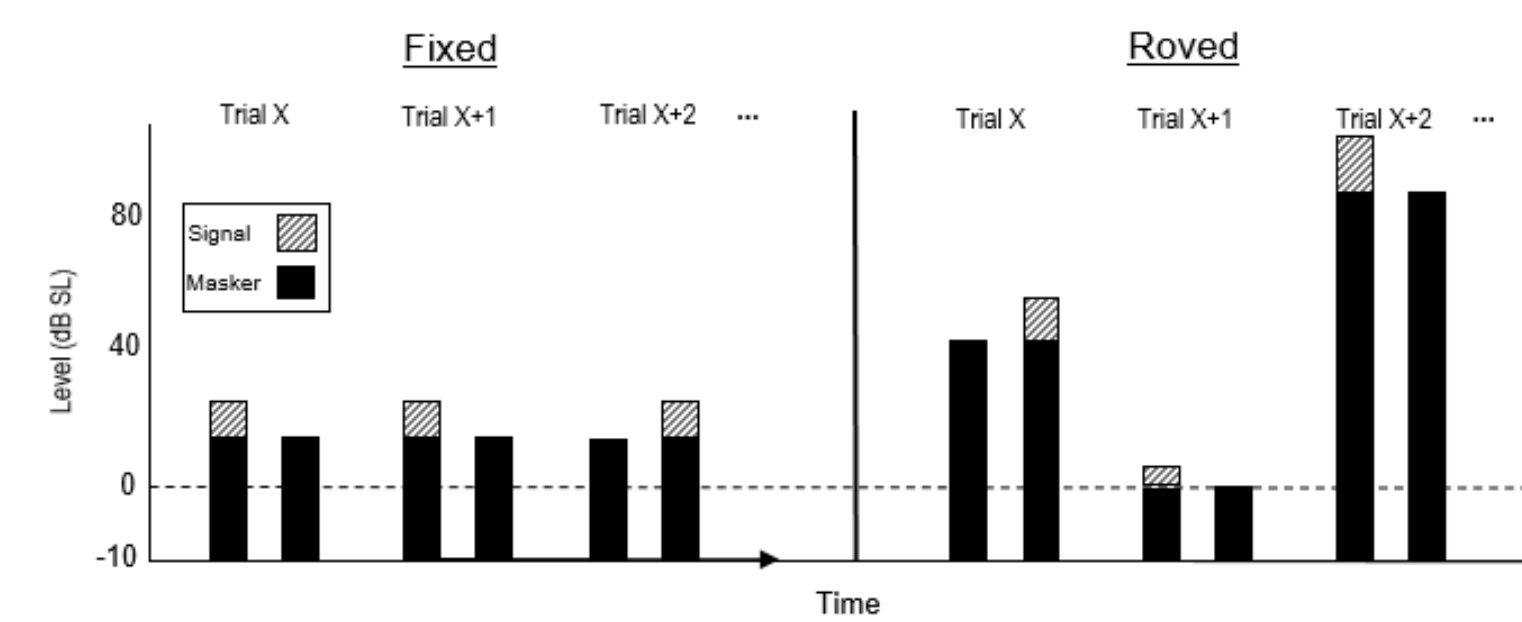


Figure 2. Schematic of two-interval paradigm in the fixed and roved conditions. In the roved condition, the masker was roved in level.

RESULTS AND DISCUSSION

Masking functions

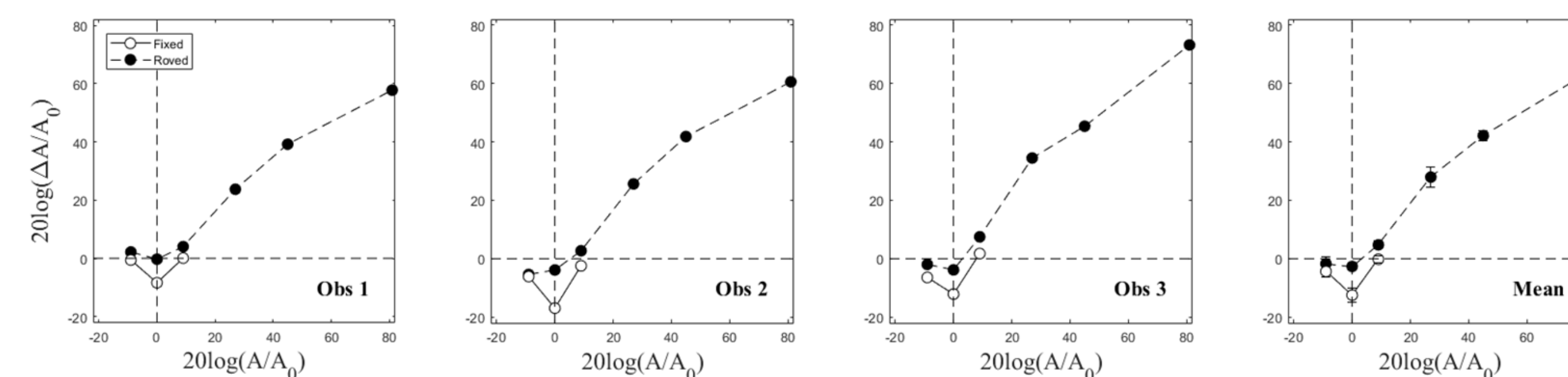


Figure 3. Masking functions for each observer and the mean across observers obtained in the fixed (open circles, solid lines) and roved (closed circles, dashed lines) conditions. Error bars are standard errors of the mean. All data are normalized to the observer's absolute detection threshold, A_0 , and therefore both the ordinate and abscissa are in units of dB SL. Points that fall below the horizontal dashed line indicate NM—i.e., ΔA at threshold is below A_0 .

- All three observers obtained NM in the fixed condition yet it was greatly attenuated in the roved condition. The magnitude of attenuation is captured by the derived measure roving cost.
- The attenuation of NM in the roved condition supports the notion that "minimal uncertainty conditions" are required to achieve NM.
- Results can also be considered in terms of gain control (e.g., Wen et al., 2009), which is conceptually related to uncertainty (i.e., ability to improve sensitivity based on stimulus context).

	Obs 1	Obs 2	Obs 3	Mean
Fixed				
Threshold (dB SL)	-8.4	-16.9	-12.1	-12.5
Roved				
Threshold (dB SL)	-0.3	-3.9	-3.8	-2.7
Roving cost at dip (dB)	8.1	13.1	8.3	9.8

Table 1. Thresholds and roving cost—the increase in threshold in the roved condition relative to the fixed condition—for 0 dB SL maskers, the point of maximum NM for all observers. Negative threshold values can be taken as the magnitude of NM.

Psychometric functions

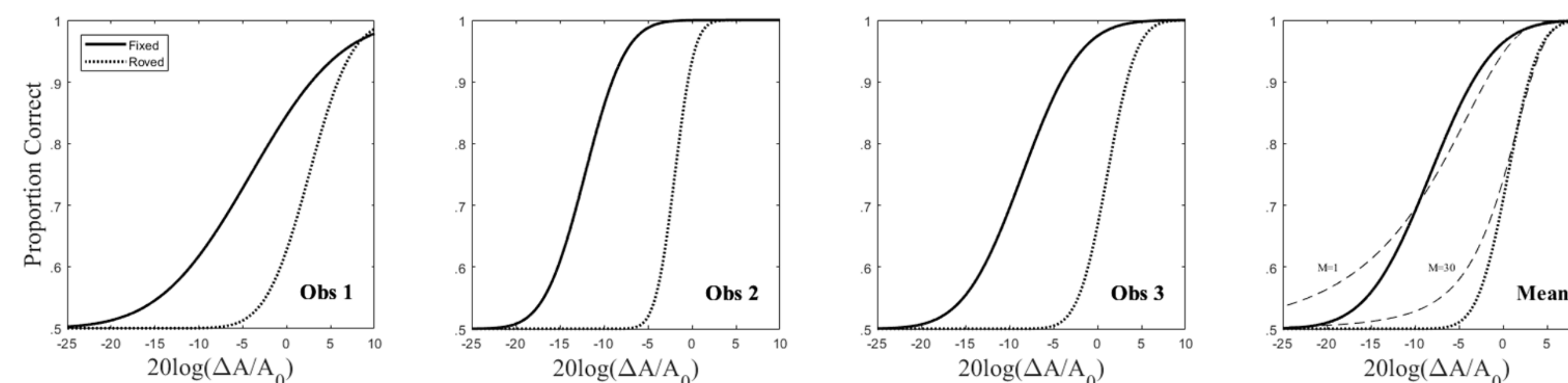


Figure 4. Psychometric functions (Gaussian fit) to the adaptive data for 0 dB SL maskers. Note that these functions were not forced to yield the same threshold as the adaptive procedure (compare Table 1 and Table II). The mean plot also shows predicted functions based on Pelli's (1985) maximum likelihood uncertainty model, one of many possible under the CUH. M , the uncertainty parameter, is the total number of monitored channels. Here, the predicted functions were shifted so that when $M=1$ the threshold (70.7%) matches the fitted mean function.

- Increased slopes in the roved condition are consistent with predictions of the CUH. Psychometric functions generated with the Pelli (1985) maximum likelihood uncertainty model are qualitatively similar to the fitted functions.
- But, does it make sense to consider level uncertainty in terms of the CUH, i.e., non-optimal processing across bands?
- "Level-bands"?
- Spread of excitation? At high masker levels, information is carried in greater number of bands across frequency. Monitoring all bands in the roved condition regardless of masker level on a given trial would result in monitoring of many uninformative channels on low masker level trials.

	Obs 1	Obs 2	Obs 3	Mean
Fixed				
Threshold (dB SL)	-5.7	-12.9	-9.6	-9.4
Slope (PC/dB)	0.02	0.05	0.04	0.04
Roved				
Threshold (dB SL)	1.8	-2.3	0.6	0.0
Slope (PC/dB)	0.05	0.11	0.08	0.08
Roving cost at dip (dB)	7.5	10.6	10.2	9.4

Table 2. Thresholds (70.7% point of the fitted functions) and slopes (in proportion correct per dB) for the fitted psychometric functions shown in Figure 4. Roving cost at dip recalculated based on psychometric functions.

EXPERIMENT 2

METHODS

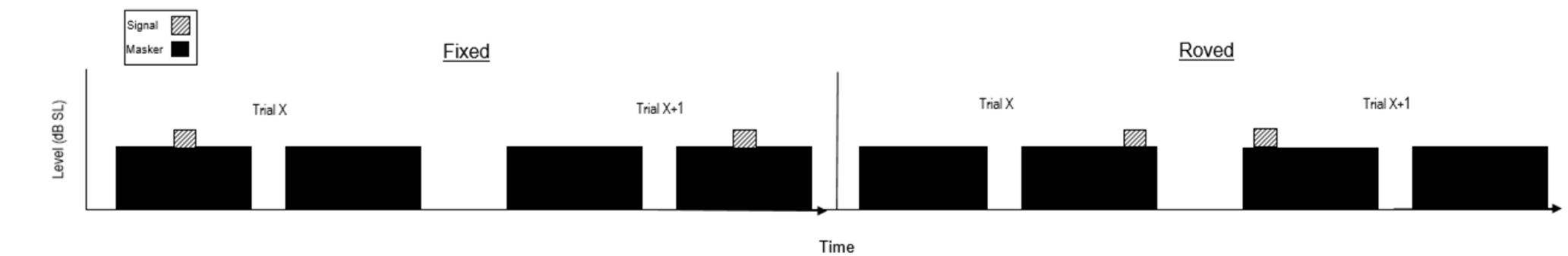


Figure 5. Schematic of two-interval paradigm in the fixed and roved conditions. In the roved condition, the signal was roved in time.

Masker levels

- Fixed and roved:** -9, 0, 9 dB SL

Rove

- Signal onset roved** in time relative to masker onset

RESULTS AND DISCUSSION

- NM was not obtained, even in the fixed condition. Thresholds were consistently poorer in the roved condition, but only slightly (**Fig. 6**).
- Psychometric functions showed no clear pattern across observers, or changes with uncertainty (**Fig. 7**).
- Possible interpretations of the lack of NM even in the fixed condition:
 - Signal duration effects:** The signal was 40-ms while the masker was 500-ms. NM is highly sensitive to the level of the masker relative to detection threshold. Here, there was a mismatch between signal dB SL and masker dB SL thus the abscissa in **Fig. 6** and **7** may be misleading. Furthermore, previous authors have found an increase in NM with signal duration (e.g., Raab et al., 1963b). Studies that have found NM under similar conditions have used longer duration signals and typically continuous (i.e., not gated) maskers (e.g., Viemeister & Bacon, 1988).
 - Residual uncertainty:** The CUH does not specify the physical dimension along which the observer may be uncertain and indeed the observer may be uncertain along multiple dimensions. Here, while the masker may have effectively cued the signal *frequency*, there may have been residual temporal uncertainty, even in the fixed condition. However, pilot data indicate that a visual cue to signal onset/duration in the fixed condition does not appreciably change the result shown here.
- These data pose a problem for models of NM *not* based on uncertainty that predict NM under conditions such as those tested here (e.g., Laming, 1986; Hanna et al., 1986), particularly given the fact that two of the three observers tested in this experiment were also tested in Experiment 1 and *did* yield NM.

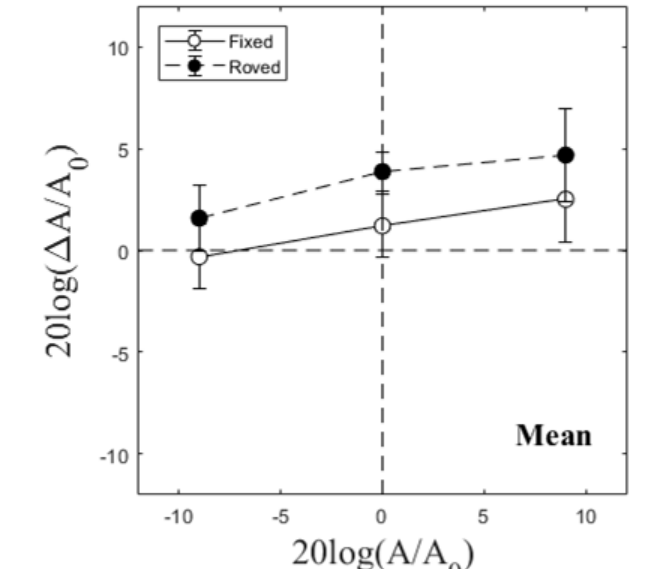


Figure 6. Masking functions

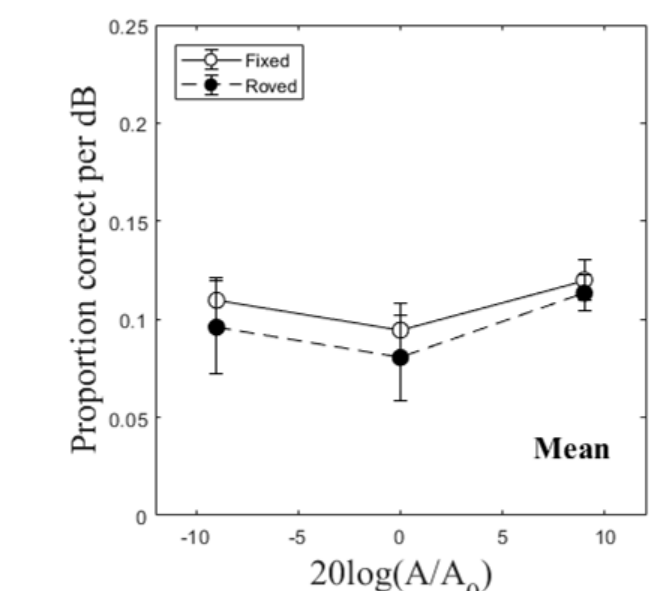


Figure 7. Psychometric function slopes

SUMMARY

- The relationship between uncertainty and NM was investigated.
- In two experiments, uncertainty was introduced into a tone-on-tone masking task in order to test the hypothesis that minimal uncertainty conditions (i.e., $M \neq 1$) are required to yield NM, as is suggested by the CUH.
- In **Experiment 1**, the introduction of uncertainty via a trial-by-trial rove of masker level greatly attenuated NM. Changes in psychometric function slopes under fixed and roved conditions support the assertion that this was due to an increase in M . These data provide qualitative support for the CUH.
- In **Experiment 2**, the introduction of uncertainty via a trial-by-trial rove of signal onset affected performance very little, and NM was not obtained, on average, even in the fixed condition. Two interpretations of these findings were offered: signal duration effects and the residual temporal uncertainty.
- The lack of NM in Experiment 2 challenges models of NM *not* based on uncertainty.
- Taken together, the results of the present study lend support to the CUH and an uncertainty-based interpretation of NM.

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