# Amplitude-Modulated Forward Masking in Listeners with Normal and Impaired Hearing

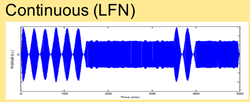
Adam Svec[3], Magdalena Wojtczak[2], Peggy B. Nelson[1]

Center for Applied and Translational Sensory Science, University of Minnesota[1]; Department of Psychology, University of Minnesota[2]; Starkey Hearing Technologies[3]

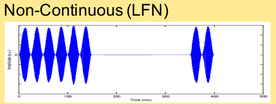
## Introduction

- In a previous study [8], excess forward masking due to inherent masker envelope fluctuations was larger for listeners with hearing loss (HI) than for those with normal hearing (NH) at relatively long masker-signal delays, suggesting that the masking effects from inherent envelope fluctuations persist to a greater degree and duration for HI than NH listeners, at least in regions of hearing loss.
- These results suggest that some mechanism other than forward masking alone is likely contributing to the differences between NH and HI listeners. It is conceivable that HI listeners may be more susceptible than NH listeners to the sequential effects of modulations in a masker envelope.
- Sequential modulation masking, or **amplitude-modulation (AM) forward masking** [9,10], may be contributing to some of the observed differences between forward maskers which have maximal (Gausian Noise; **GN**) or minimal (Low-Fluctuation Noise; **LFN** [3,4]) inherent envelope fluctuations.
- For this reason, the current study measured **AM forward masking** for both NH and HI listeners at 4000 and 1000 Hz, using continuous (LFN) and non-continuous (LFN or GN) masker and signal (LFN) carriers.

Continuous (LFN)



Non-Continuous (LFN)



### Hypotheses

- For the Continuous Carrier conditions, based on previous results [5,8], we hypothesized that **AM forward-masked modulation detection thresholds (MDTs)**:
  - Would be elevated at longer masker-signal delays for HI relative to NH listeners at **4000 Hz**, suggesting that AM forward masking may be contributing to excess disruptions experienced by HI listeners after the offset of a masker in the modulation masking domain.
  - At **1000 Hz**, HI listeners would be more similar to NH listeners, due to less hearing loss in that region.
- For the Non-Continuous Carrier conditions, we hypothesized that:
  - Unmodulated LFN conditions would yield less AM forward masking than the unmodulated GN.
  - The AM LFN and unmodulated GN would yield more AM forward masking for the HI than NH listeners.

## Participants

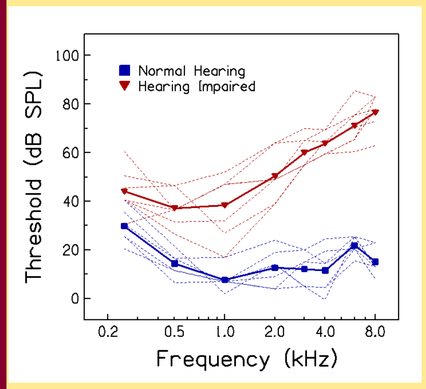



***Figure 1:*** Mean (filled symbols) and individual (dashed lines) pure-tone thresholds measured (in dB HL, converted to dB SPL [1]) in the test ear for ~250-ms signals for NH and HI participants.

### Participants

- NH: n=7, Age 19-35
- HI: n=7, Age 59-79
- Listeners with a conductive component to their hearing loss were not eligible for participation.
- Listeners were compensated for their participation.

## Methods

### Apparatus and Stimuli

### Continuous Carrier Conditions

- Carrier: 500-ms, 1/3 ERB LFN centered at either 4000 Hz (3924-4077 Hz) or 1000 Hz (978-1022 Hz).
- Signal: 50-ms, 40-Hz sinusoidal amplitude modulation (SAM) imposed on the 500-ms carrier.
- Maskers: 150-ms, 40-Hz SAM imposed on same 500-ms carrier that contained the signal.
- Masker-Signal Delays: 50, 100, or 200 ms.
- Level: 80 dB SPL. Modulation depth for the masker was fixed at 0 dB (20 log m, m = modulation index). Both masker and signal modulations began at 0-rad (sine) phase.

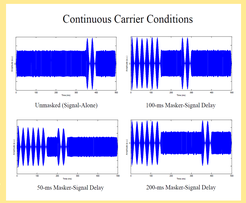



***Figure 2.*** Waveforms showing 500-ms LFN carriers for the unmasked (top left) and masked conditions. The separation of the 150-ms 40 Hz AM masker from the 50-ms 40 Hz AM signal is shown at masker-signal delays of 50 (bottom left), 100 (top right), and 200 (bottom right) ms.

### Non-Continuous Carrier Conditions

- Carrier: 150-ms (masker) or 50-ms (signal) 1/3 ERB GN or LFN centered at 4000 Hz (3924-4077 Hz).
- Signal: 50-ms, 40-Hz SAM imposed on a 50-ms carrier, 5-ms raised-cosine onset/offset ramps.
- Masker: 150-ms unmodulated GN, LFN, or 40-Hz SAM LFN masker, 5-ms raised-cosine onset/offset ramps.
- Masker-Signal Delay: 200 ms for each masker condition, which contained silence.
- Conditions:
  1. Signal-Alone
  2. Unmodulated LFN (U-LFN)
  3. Unmodulated GN (U-GN)
  4. 40 Hz AM-LFN

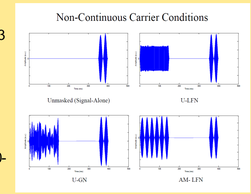



***Figure 3.*** Waveforms showing the brief 50-ms 40 Hz AM signal in each panel, including the unmasked condition (top left). The three types of 150-ms maskers are shown in the other three panels: unmodulated Gaussian noise (U-GN, bottom left); unmodulated low-fluctuation noise (U-LFN, top right); and 40 Hz AM low-fluctuation noise (AM-LFN, bottom right). The masker-signal delay for each masker condition is 200 ms.

## Procedure and Data Analyses

### Procedure

- Both unmasked and masked MDTs measured using a 3IFC, 3-down, 1-up, procedure adapting on signal modulation depth and tracking the 79.4% correct point on the psychometric function [6].
- Modulation depth of the signal set to 0 dB at the beginning of each trial, decreasing by 4 dB after two correct answers, and increasing by 4 dB after one incorrect answer. After 4 reversals, step size reduced to 2 dB until 8 reversals were measured, completing the trial after 12 reversals. MDTs were the average of signal modulation depths over the final 8 reversals. Three thresholds were gathered to estimate MDT.
- Stimuli were generated at a sampling rate of 44.1 kHz via MatLab on a PC matched with a Lynx TWO-B soundcard and a DAC1 D/A converter, and presented monaurally to the listener through a Tucker-Davis Technologies (TDT) HB6 headphone buffer driving a Sennheiser HD650 circumaural earphone.

### Data Analyses

- For the Continuous Carrier results, effects of center frequency (1000, 4000 Hz) and masker-signal delay (50, 100, 200 ms) were assessed with a repeated-measures ANOVA in SPSS using the general linear model, including one between-subjects factor (NH vs. HI).
- For the Non-Continuous Carrier results, each of the four conditions were treated as a level of a within-subjects factor (NM, U-LFN, U-GN, AM-LFN) for the repeated-measures ANOVA, including one between-subjects factor (NH vs. HI).
- Post-hoc tests for planned comparisons were used to determine differences between NH and HI listeners for U-LFN vs. U-GN, U-LFN vs. AM-LFN, and AM-LFN vs. U-GN, as well as for unmasked thresholds (continuous vs. non-continuous).

## Results

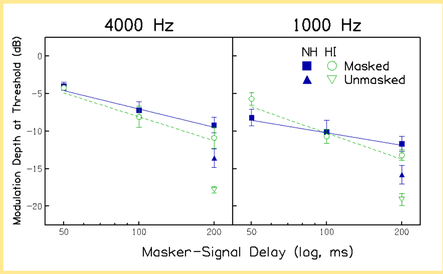



**Figure 4.** Mean AM forward-masked modulation detection thresholds (MDTs), or modulation depth at threshold (in dB), for the low-fluctuation noise (LFN) continuous carrier conditions at two center frequencies, 4000 (left) and 1000 (right) Hz, and at three masker-signal delays (50, 100, 200 ms) are plotted for NH (filled squares, solid lines) and HI listeners (filled circles, dashed lines). Mean unmasked MDTs for NH (filled triangles) and HI (filled inverted triangles) are plotted at a masker-signal delay of 200 ms. Individual masked and unmasked thresholds are plotted with the corresponding open symbols.

### Continuous Carrier (*Fig. 4*)

- Masked MDTs were significantly better at 1000 Hz than at 4000 Hz for both listener groups.
- Main effects of Center Frequency [F(1, 12) = 20.898, p<0.05] and Masker-Signal Delay [F(1, 12) = 58.518, p<0.001].
- Two-way interaction of Masker-Signal Delay & Listener group [F(2, 24) = 3.584, p<0.05], suggesting the slightly steeper slopes of recovery for HI than NH listeners may be driving this interaction at both 1000 (NH = -0.02, HI = -0.05) and 4000 (NH = -0.03, HI = -0.04) Hz.
- However, no overall effect of listener group [F(1, 12) = 0.108, p>0.05].

**Post-hoc tests** for planned comparisons:

- Unmasked MDTs for the Continuous Carrier were better for HI than for NH listeners at both 4000 (p<0.05) and 1000 Hz (p<0.05).
- No differences between NH and HI listeners for any of the masked conditions (p>0.05).

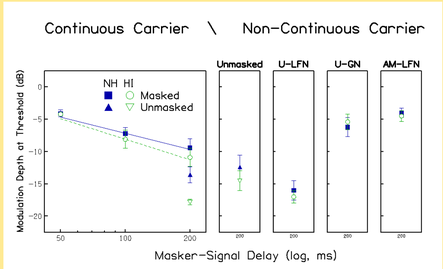



***Figure 5.*** Mean and individual AM forward-masked modulation detection thresholds (MDTs), or modulation depth at threshold (in dB), for the same continuous carrier conditions from Fig. 4. for 4000 Hz (first panel) at three masker-signal delays (50, 100, 200 ms) are plotted for NH (squares, solid lines) and HI listeners (open circles, dashed lines). For the non-continuous carrier conditions for 4000 Hz, the same symbols are used to plot MDTs for the Unmasked (second panel), unmodulated LFN masker (U-LFN, third panel), unmodulated GN masker (U-GN, fourth panel), and the 40 Hz amplitude-modulated LFN masker (AM-LFN, fifth panel) conditions.

### Non-Continuous Carrier (*Fig. 5*)

- Main effects of Masker envelope condition [F(3, 24) = 94.050, p<0.001]
- No difference between NH and HI listeners [F(1, 8) = 0.226, p>0.05].

**Paired comparisons** across carrier types and within groups:

- No differences between the unmasked thresholds for Continuous and Non-Continuous Carrier conditions for either NH or HI listeners (p>0.05).
- U-GN masker yielded significantly more masking than the U-LFN masker (p<0.05), and the U-GN and AM-LFN maskers produced comparable masking (p>0.05).
- Non-Continuous Carrier yielded significantly more masking (NH = 5.4 dB, HI = 5.1 dB) than the Continuous Carrier when assessing the AM-LFN condition at a masker-signal delay of 200 ms for both NH (p<0.05) and HI (p<0.05) listeners.
- No differences were observed between listener groups (p>0.05).

## Results

### Primary Findings

- Masked MDTs improved as masker-signal delay increased for both groups, as previously observed [9,10].
- In line with predictions, an unmodulated GN masker yielded significantly more masking than an unmodulated LFN, suggesting that inherent masker envelope fluctuations contributed to the amount of AM forward masking across listener groups.
- Contrary to predictions, results suggested there were no differences in the amount of AM forward masking between NH and HI listeners, suggesting there is little effect of hearing loss on recovery from AM forward masking.
- Notably, for the Non-Continuous Carrier conditions, masked MDTs for both NH and HI listeners were substantially elevated relative to unmasked MDTs at a masker-signal delay of 200 ms for both AM LFN and GN maskers, suggesting some disruption of the detection cue due to the gating of the masker and/or the signal.

## Discussion

- For AM forward masking, the physical level of the signal is not changing, only its modulation depth. It has been shown that, likely due to a more linear response of the basilar membrane, HI listeners are often just as well equipped to detect amplitude modulations of a signal at suprathreshold levels [2].
- In this situation, the linear response of the basilar membrane may actually aid the HI listeners in detecting the peaks and valleys of subtle amplitude modulations. At an overall level of 80 dB SPL, both NH and HI listeners were subjected to stimuli that were well above hearing thresholds.

### Conclusions

1. AM forward masking was observed for both HI and NH listener groups, with no difference between groups.
2. For the unmasked continuous carrier conditions, better MDTs were yielded for HI than NH listeners.
3. For the masked continuous and non-continuous carrier conditions, NH and HI listeners performed very similarly, suggesting there is a little effect of hearing loss on the magnitude of AM forward masking.
4. For the non-continuous carrier, the unmodulated GN yielded more masking than the unmodulated LFN, suggesting that inherent masker envelope fluctuations contributed to the amount of AM forward masking across listener groups.
5. The continuous carrier resulted in better masked MDTs for the amplitude-modulated LFN masker than the non-continuous carrier, suggesting that AM forward masking is increased by the envelope modulation resulting from gating the masker carrier.

### Future Directions

- Because sequential temporal cues remained relatively robust for this group of HI listeners, investigating the effects of multi-channel compression, as is often prescribed for a hearing aid fitting formula, for these same conditions may allow for examining whether or not compressed output of a hearing aid disrupts these cues.

## Acknowledgments and References

Work supported by the Bryng Bryngelson Research Fund in the Department of Speech-Language-Hearing Sciences, University of Minnesota.

1. ANSI (**2004**). ANSI S3.6-2004, Specifications for audiometers (American National Standards Institute, New York).
2. Bacon, S. P., and Gleitman, R. M. (**1992**). "Modulation detection in subjects with relatively flat hearing losses," J. Sp. Lang. Hear. Res. **35**, 642-653.
3. Hartmann, W. M., and Pumplin, J. (**1988**). "Noise power fluctuations and the masking of sine signals," J. Acoust. Soc. Am. **83**, 2277-2289.
4. Kohlrausch, A., Fassel, R., van der Heijden, M., Kortekaas, R., van de Par, S., Oxenham, A. J., and Püschel, D. (**1997**). "Detection of tones in low-noise noise: Further evidence for the role of envelope fluctuations," Acta. Acust. United AC. **83**, 659-669.
5. Koopman, J., Houtgast, T., and Dreschler, W. A. (**2008**). "Modulation detection interference for asynchronous presentation of masker and target in listeners with normal and impaired hearing," J. Sp. Lang. Hear. Res. **51**, 1588-1598.
6. Levitt, H. (**1971**). "Transformed up-down methods in psychoacoustics," J. Acoust. Soc. Am. **49**, 467-477.
7. Svec, A., Dubno, J. R., and Nelson, P. B. (**2015; a**). "Effects of inherent envelope fluctuations in forward maskers for listeners with normal and impaired hearing," J. Acoust. Soc. Am. **137**, 1336-1343.
8. Svec, A., Dubno, J. R., and Nelson, P. B. (**2015; b**). "Inherent fluctuations in forward maskers: Effects of masker-probe delay for listeners with normal and impaired hearing," Poster session presented at the biannual meeting of the Association for Research in Otolaryngology, Baltimore, MD. J. Assoc. Res. Otolaryngol., February 2015.
9. Wojtczak, M., and Viemeister, N. F. (**2005**). "Forward masking of amplitude modulation: Basic characteristics," J. Acoust. Soc. Am. **118**, 3198-3210.
10. Wojtczak, M., Nelson, P. C., Viemeister, N. F., and Carney, L. H. (**2011**). "Forward masking in the amplitude-modulation domain for tone carriers: psychophysical results and physiological correlates," J. Assoc. Res. Otolaryngol. **12**, 361-373.