Comodulation masking release and monaural envelope correlation perception in listeners with cochlear hearing loss

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This study investigated the comparative dependence of comodulation masking release (CMR) and monaural envelope correlation perception (MECP) on the degree of envelope similarity in pre-senescent adult listeners with normal hearing (NH) or mild-to-moderate cochlear hearing loss (CL). A 1600-Hz pure-tone signal was used to measure CMR as a function of degree of envelope correlation in 100-Hz-wide noise bands centered at 727, 1093, 1600, 2300, and 3268 Hz. The same noise band configuration was used to measure MECP thresholds for both comodulated and independent standards. Envelope correlation was adjusted by mixing comodulated and independent maskers at variable intensity ratios. The five-band complex was 85 dB SPL. Signal thresholds improved monotonically (i.e., CMR increased) with increasing degrees of envelope correlation for all listeners. Results for CL listeners were most similar to data from previous NH listeners at a 72 dB SPL masker level. For MECP, performance patterns for the two conditions were uniform across NH listeners, whereas those for CL listeners exhibited greater individual differences. Finally, CMR and MECP performance appeared to be related in listeners with CL. The pattern of results will be discussed in terms of the effects of CL on sensitivity to envelope similarity. (Work supported by NIDCD R01DC001507.)

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INTRODUCTION

Reduced compression in the ear with cochlear hearing loss (CL) might be expected to result in altered temporal envelope processing. Two phenomena that rely on envelope processing are comodulation masking release (CMR) and monaural envelope correlation perception (MECP). Both phenomena rely on a sensitivity to across-frequency correlation, or comodulation, of temporal envelopes. Although each phenomenon has been examined separately in CL listeners, the purpose of this study was to compare CMR and MECP in these listeners for the same stimulus configurations. The particular focus was the relative dependence of these two phenomena on the degree of envelope correlation across frequency.

A common measure of CMR is the reduction in masked threshold for a pure-tone signal in a masker comprising a complex of comodulated noise bands relative to one where the noise bands are independent across frequency. Reduced CMR for CL listeners relative to listeners with normal hearing (NH) has been observed in some circumstances. For example, Hall & Grose (1994) showed that CL listeners had reduced CMR for a 1000-Hz pure-tone masked by six harmonically-spaced 20-Hz-wide maskers. Similarly, using a band-widening measure of CMR, Hall et al. (1988) found reduced CMR for CL listeners in a 1000-Hz-wide masker centered at 1000 Hz. However, in that same study, Hall et al. (1988) found no significant differences between CL listeners and NH listeners for masker bandwidths ≤ 400 Hz. These results are consistent with the hypothesis that across-frequency comparison of temporal envelopes may be restricted for CL listeners due to broad auditory filters.

The measure of MECP refers to a listener’s ability to discriminate complexes of noise bands on the basis of their relative envelope patterns – typically comodulated vs. random. Hall & Grose (1993) found similarities in MECP for CL listeners and NH listeners for conditions that included 100-Hz wide noise bands separated by 500 Hz or 1000 Hz. However, they found poorer MECP in CL listeners for conditions in which noise bands were separated by only 250 Hz. Like results from CMR studies, results from MECP studies are consistent with the suggestion that broad auditory filters for CL listeners could negatively influence performance for conditions in which noise bands are relatively closely spaced.

Recent work in our lab has looked at the association between CMR and MECP in NH listeners. This study investigated the comparative dependence of CMR and MECP on degree of envelope similarity in pre-senescence adult CL listeners.

METHODS

Participants included eight listeners with mild-to-moderate hearing loss, with a mean age of 50.7 years (standard deviation = 15.0 years). Air conduction thresholds for the test ear of CL listeners are shown in Table 1.

<table>
<thead>
<tr>
<th>Subject</th>
<th>250</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>4000</th>
<th>8000</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>30</td>
<td>31.3</td>
<td>38.1</td>
<td>40.6</td>
<td>45</td>
<td>50.6</td>
</tr>
<tr>
<td>SD</td>
<td>14.4</td>
<td>11.9</td>
<td>9.2</td>
<td>7.3</td>
<td>13.1</td>
<td>17.2</td>
</tr>
</tbody>
</table>

Stimuli

A 1600-Hz pure-tone signal, 300 ms in duration including 20-ms onset/offset ramps, was used to measure CMR. Noise bands for the CMR masker and MECP task were 100 Hz wide and centered at 727, 1093, 1600, 2300, and 3268 Hz. The noise bands were generated with a sampling rate of 12,207 Hz using a digital signal processing platform (RPvds, Tucker-Davis Technologies).

Two base sets of masker bands were generated using a quadrature multiplication technique: a 5-band complex of comodulated bands and a complementary 5-band complex of independent bands. Additional 5-band complexes with systematically varied envelope correlation were created by mixing the two base masker sets to produce six complexes with comodulated-to-independent masker ratios of 0, 5, 15, 20, and 25 dB. Waveform envelope pairwise Pearson correlation coefficients associated with these prescribed comodulated-to-independent noise ratios were r = 0.23, 0.55, 0.81, 0.93, 0.98, 0.99. The masker complex was presented at 85 dB SPL.
Procedure

Signal thresholds were measured using a 3-alternative, forced-choice (3AFC) procedure that incorporated an adaptive 3-down, 1-up stepping rule to obtain 79.4% correct. The noise bands were gated on for 368 ms including 34-ms raised-cosine ramps in each interval.

For the CMR task, the 300-ms signal was temporally centered in the masker and presented at random in one of the three observation intervals. At least three estimates of threshold were collected; a fourth being collected if the difference in threshold between tracks exceeded 3 dB. The mean of all collected estimates was taken as the final estimate of threshold.

For the MECP task, the target interval was presented at random in one of the three observation intervals. Depending on the condition, the other two intervals comprised either the fully-comodulated bands or the fully-independent bands. Comodulated-to-independent ratio for the target was adaptively varied using a scaling factor that controlled the proportion with which the base sets of comodulated and independent bands were mixed in the power domain to form the target. At least three estimates of threshold were collected; a fourth being collected if the scaling factor at threshold differed between tracks by an amount exceeding 0.15. The mean of all collected estimates was taken as the final estimate of threshold. Training was incorporated into the MECP task consisting of a non-adaptive procedure in which the target interval was always known. This allowed the listener to repeatedly compare the target to the non-target bands. Training was provided only for the MECP task, as the CMR task included relatively salient cues.

RESULTS

Signal threshold for the 1600-Hz pure tone in masking noise improved monotonically with increasing degree of envelope correlation until reaching a lower asymptote (Fig. 1).

![Graph](image)

**FIGURE 1.** Signal threshold plotted as a function of comodulated-to-independent ratio (lower axis) and the associated envelope correlation coefficient (upper axis). Error bars are 1 standard deviation (SD).

This finding was supported by a repeated measures analysis of variance (ANOVA) that indicated a significant effect of masker condition on signal threshold ($F[7,98]=23.91, p \leq 0.001$). Pre-planned contrasts indicated that the decline in threshold relative to threshold in the independent band condition first became significant at a comodulated-to-independent ratio of 10 dB ($t[1,7]=2.90, p=0.02$). Additional pre-planned contrasts suggested data reach a lower asymptote at a comodulated-to-independent ratio of 15 dB, as significant differences in threshold were not found for sequential pairs higher than 15 dB ($p \geq 0.05$). The error bars in Figure 1 indicated that inter-listener variability was relatively high for the CL listeners.
Data for this study were collected subsequent to data collection in a similar CMR study using NH listeners. Magnitude of CMR was calculated by subtracting threshold for each comodulated-to-independent ratio greater than or equal to zero from threshold in the independent band condition. The study parameters were identical to the present study with the exception that stimuli were presented to NH listeners at 72 dB SPL (i.e., 65 dB per band). Figure 2 shows CMR as a function of degree of envelope correlation for CL listeners collected at 85 dB SPL and previously collected data from NH listeners at 72 dB SPL.

Less variability in CMR is apparent for NH listeners compared to CL listeners. In addition, data from CL listeners collected at 85 dB SPL are similar to data collected from NH listeners at 72 dB SPL. This notion was supported by a repeated measures ANOVA that showed a significant effect of condition ($F[7,84]=33.08$, $p \leq 0.001$), but no significant effect of group ($F[1,12]=0.003$, $p=0.96$) or group x condition interaction ($F[7,84]=2.65$, $p=0.44$).

Results for CL listeners who completed the MECP paradigm are shown in Figure 3.
FIGURE 3. Monaural envelope correlation perception (MECP) thresholds for the comodulated (COMOD) and independent (IND) standard conditions for listeners with cochlear hearing loss (CL). The left axis shows comodulated-to-independent ratio and the right axis shows the corresponding correlation coefficient. In addition to the individual data (one symbol per subject), the box plots show the 25th-75th percentiles, with the horizontal lines indicating the median, and the upper and lower caps showing the extreme values.

One CL listener was unable to detect a difference in correlation when presented with the fully-independent set of bands as a standard for comparison; one was unable to detect a difference when presented with the either the fully-independent or the fully-comodulated set of noise bands as a standard. Individual differences in relative performance between the comodulated and independent standard conditions were noted for CL listeners who were able to complete both tasks.

Average MECP threshold for the comodulated standard condition was 6.6 dB (standard deviation = 3.3). This represents the average comodulated-to-independent ratio at which CL listeners could detect that the envelopes across the five noise bands were no longer fully-comodulated. Threshold for the independent standard condition, representing the comodulated-to-independent ratio at which listeners could detect that the envelopes across the five noise bands were no longer fully-independent, was 8.8 dB (standard deviation = 3.1). Threshold for the comodulated standard and the independent standard were not significantly different (t[5]=1.33, p=0.24).

Figure 4 shows CMR as a function of MECP for the comodulated standard condition (filled circles) and for the independent standard condition (open squares).

FIGURE 4. Comodulation masking release (CMR) as a function of monaural envelope correlation perception (MECP) thresholds for comodulated standard conditions (filled circles) and independent standard conditions (open squares) for listeners with cochlear hearing loss (CL).

Pearson correlations were significant (one-tailed) for magnitude of CMR and threshold for both the comodulated standard condition ($r=0.67$, $p\leq 0.05$) and the independent standard condition ($r=0.80$, $p\leq 0.05$).

Data collection in NH listeners is currently in progress for identical CMR and MECP paradigms as those used for the CL listeners described above (i.e., using presentation levels of 85 dB SPL). At present, these data suggest signal threshold improves monotonically with increasing degree of envelope correlation and relatively uniform MECP performance across the two conditions.

DISCUSSION

This study investigated the comparative dependence of CMR and MECP on the degree of envelope similarity in pre-senescent adult CL listeners. Increased magnitude of CMR was observed with increasing degree of envelope correlation for CL listeners. In addition, CMR was observed for bands of noise with comodulated-to-independent ratios of 10 dB, corresponding to a correlation coefficient of 0.81. This indicates that CL listeners benefit from degrees of envelope correlation that are less than $r = 1$. Interestingly, CL listeners did not obtain additional masking
release for degrees of envelope correlation greater than \( r = 0.93 \). However, these results also suggest that CL listeners first experience CMR and reach maximum CMR within a relatively narrow range of correlations. This result may have been influenced by the high variability in CL listener performance.

The pattern of results obtained for the CMR task was similar for CL listeners collected using 85 dB SPL presentation levels and NH listeners collected using 72 dB SPL presentation levels. This supports past studies suggesting reduced CMRs sometimes observed for CL listeners could be attributed to low sensation level (Mendoza et al., 1996; Moore et al., 1993). Furthermore, these data are in agreement with the hypothesis that reduced CMR for CL listeners might be limited by broad auditory filters for paradigms that include narrow spacing between masker bands (e.g., Hall & Grose, 1994).

Significant differences in MECP thresholds did not differ for the comodulated standard condition and the independent standard condition suggesting CL listeners are equally adept at detecting a change in correlation from a correlated set of bands or an independent set of bands. Threshold values for the comodulated standard (6.6 dB) and the independent standard (8.8 dB) conditions were relatively similar to the comodulated-to-independent ratio at which masking release was first evident in the CMR task (10 dB). This suggests fair agreement between the perception of envelope correlation and the amount of correlation required to obtain masking release for comodulated maskers for CL listeners.

Across-frequency temporal envelope processing is utilized in CMR and MECP tasks, suggesting some similarity in these processes. Furthermore, commonalities have been noted between sensitivity to correlation between noise bands and magnitude of CMR (Richards, 1987). Data from this study suggest an association between CMR and MECP for CL listeners, as CMR and MECP threshold were significantly associated for the fully-comodulated and the fully-independent standard conditions. However, some evidence suggests that, at least for NH listeners, CMR and MECP might rely in part on different processes. For example, bandwidth seems to affect each process differently, as CMR tends to increase and MECP sensitivity tends to decrease as bandwidth narrows (Buss et al., 2013; Moore & Emmerich, 1990). In addition, CMR is not affected by masker envelope decorrelation in some circumstances (Moore et al., 1990; Hall & Grose, 1988; Buss, 2010). These factors have yet to be investigated in listeners with CL.

**CONCLUSION**

Magnitude of CMR improved monotonically with increasing degree of envelope correlation for CL listeners. Average CMR for CL listeners was similar to previously collected data from NH listeners suggesting that CL listeners may benefit from comodulation as well as NH listeners for widely spaced noise bands at high presentation levels. Further data are being collected to examine this possibility. Similarities in the comodulated-to-independent ratio at which CMR was first observed and threshold for both MECP conditions indicates agreement between masking release for comodulated stimuli and the perception of envelope correlation for CL listeners. There was an association between magnitude of CMR and MECP threshold for both the correlated standard condition and the independent standard condition, suggesting similarity in these processes for CL listeners.

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**REFERENCES**


