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PERIPHERAL AND CENTRAL PROCESSES IN HEARING

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One of the important problem in contemporary psychoacoustics is what can be instrumental in eliminating a relatively wide gap between peripheral — within-channel — and central — across-channel — auditory processes. The authors argued that CMR and MDI — two forms of auditory masking — can be useful in clarifying this problem. The mechanisms involved in the both effects are peripheral and central as well.

1. Introduction

There is a relatively wide gap between what is known about very peripheral auditory processes (such as frequency analysis on the basilar membrane) and what is known about more complex central auditory processes (such as speech perception). Peripheral and central processes may differ in many ways. However, one possible way of characterising the difference is in terms of within-channel versus across-channel processes. In the auditory periphery, for example at the level of the auditory nerve, stimuli are represented in frequency "channels", each responding to a limited range of frequencies. There is little interaction between channels with widely separated centre frequencies. However, at more central levels of the auditory system, neurones exist which combine information from different peripheral frequency channels.

If an aspect of auditory perception can be explained entirely by consideration of processes occurring within one frequency channel, then that aspect might reflect mainly peripheral processing. However, if an aspect of auditory perception can only be explained by processes that involve comparing or combining information across frequency channels, then those processes must occur relatively centrally, at a level higher than the auditory nerve. The phenomena known under acronyms CMR (comodulation masking release) and

MDI (modulation detection/discrimination interference) may be very useful in illustrating these aspects of peripheral and central processing in hearing.

It has often been assumed that, when an observer is trying to detect a sinusoidal signal of a given frequency in a noise background, performance is based on the output of the single auditory filter (the one peripheral channel) that gives the highest signal-to-noise ratio [15]. However, this assumption clearly fails in some situations. In the phenomenon of comodulation masking release (CMR) [4], the outputs of auditory filters tuned away from the signal frequency can be used to enhance signal detection. CMR occurs when the task is to detect a signal centred in a narrow-band masker (the on-frequency band) that is amplitude modulated in some way. The addition of other components to the masker, remote from the signal frequency, can enhance signal detection, provided the extra components have a similar pattern of modulation to the on-frequency band. These extra masker components are sometimes called "flankers". CMR is usually assumed to reflect a relatively central across-channel process.

In the phenomenon of modulation detection/discrimination interference (MDI), the outputs of auditory filters tuned away from the signal frequency degrade signal detection. This degradation seems to happen mainly when the task of the observer is to discriminate changes in modulation depth of the signal or to detect a change in the modulation pattern of the signal [11, 12, 19]. The ability to discriminate/detect these changes is adversely affected by the presence of other modulated sounds (also called flankers, but sometimes also called "interferers"), even when those sounds have centre frequencies well away from that of the target. Again, MDI is usually assumed to reflect a relatively central across-channel process.

Results from CMR experiments were initially surprising, primarily because the paradigm used to measure the effect had previously been associated with highly successful within-channel explanations that were based upon peripheral auditory processes. If the initial results are viewed in the context of central auditory analyses, they are no longer so unexpected. In fact, the surprise may be that within-channel explanations based on the concept of the auditory filter can account so much data on auditory masking. But there may be another way of looking at this. If the within-channel model is so successful, perhaps peripheral, within-channel mechanisms contribute to CMR and MDI [18]. Exploration of the relative importance of within-channel and across-channel processes in CMR and MDI may shed light on the peripheral versus central nature of these processes.

2. Evidence for central across-channel processes

2.1. Effects of monaural versus dichotic presentation

Both CMR and MDI can occur when the flankers are presented dichotically, i.e. to the ear opposite that receiving the target sound. This clearly demonstrates that part of the CMR and MDI effects must depend upon central processes. These dichotic effects, however, have generally been less than those for monaural presentation [1, 17]. The difference between the monaural and dichotic effects may reflect contributions from peripheral, within-channel processes.

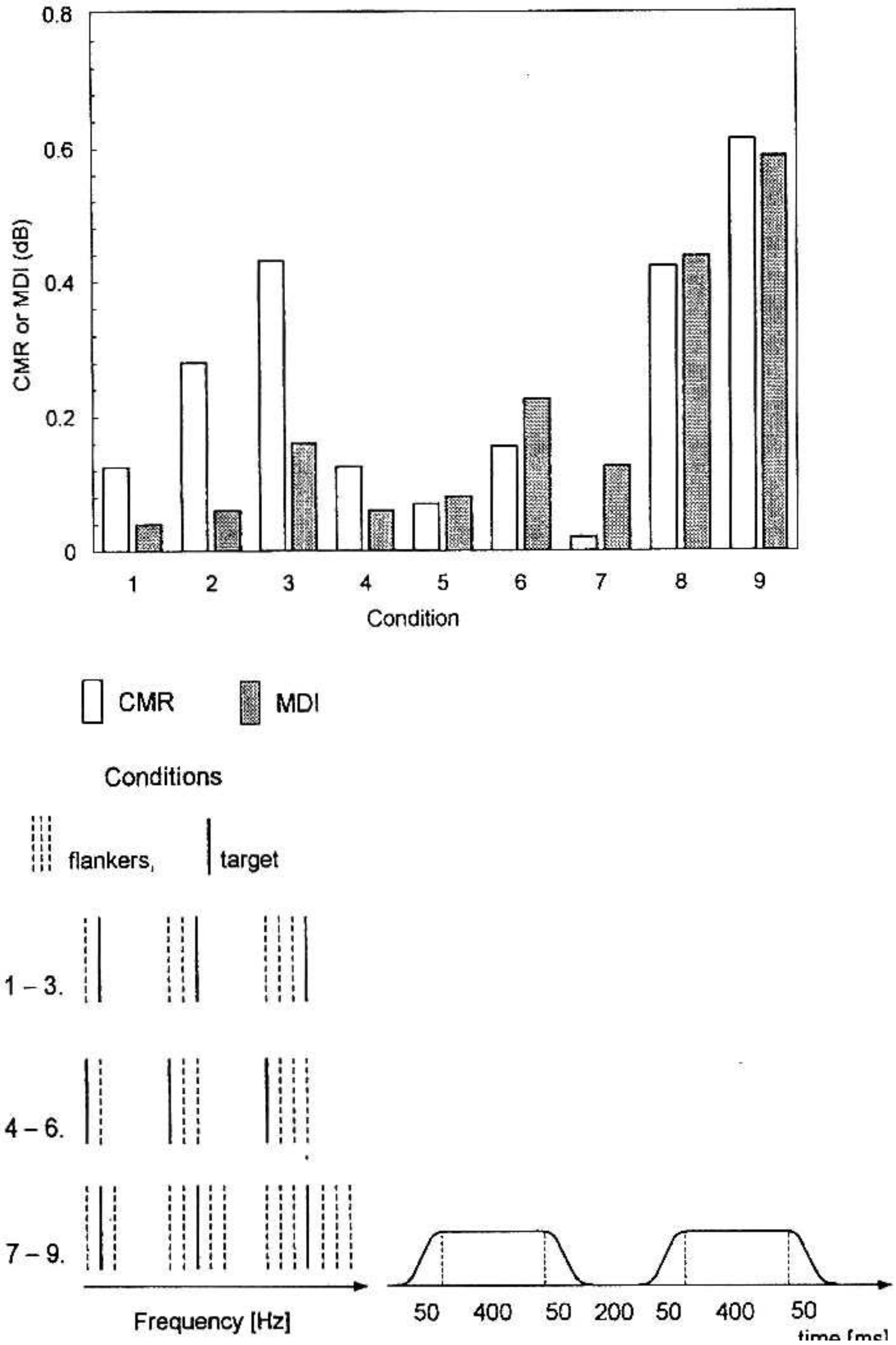

Fig. 1. The amount of CMR or MDI. The cartoons show schematically the spectra of the target and flankers for all conditions, time paradigm of signals, and their presentation in each forced-choice trial. Results shown are the average for three subjects (from [12]).

2.2. Effects of the number and spectral location of the flankers

One way of exploring the relative role of within and across-channel processes is to measure how the amount of CMR or MDI is influenced by the number of flankers and by the frequency separation of the flankers from the target. If CMR and MDI are mainly determined by within-channel processes, large effects should be produced by flankers close to the target frequency, and adding further flankers more remote from the target frequency should have little effect. MOORE and JORASZ [12] tested this prediction.

The target carrier frequency was 1000 Hz, and flanker carrier frequencies were: 416, 572, 765, 1301, 1670, and 2127 Hz. Both the target and the flankers were sinusoids which were amplitude modulated by narrow-band noise extending from 5 to 15 Hz. The overall intensity was held constant (level = 60 dB SPL per carrier) regardless of modulation depth. In one condition, called "comodulated", the flankers were all modulated in the same way (i.e. with the same modulator) as the target. In a second condition, called non-comodulated, the flankers were all modulated in the same way as each other, but the target was modulated by an independent narrowband noise. For the CMR task, the subject was required to detect a 1000-Hz sinusoid added to the 1000-Hz noise-modulated carrier. The MDI task was to detect a decrease in modulation depth of the target. The target and masker carriers were gated together; in the CMR task, the signal was gated synchronously with the target and masker carriers.

Figure 1 shows schematic spectra of the stimuli (bottom left), the time pattern of the stimuli (bottom right) and the experimental results (top). Both MDI (filled bars) and CMR (open bars) increased with an increase in the number of flanking bands. In other words, adding flankers more remote from the target frequency led to larger effects. This suggests that both CMR and MDI are influenced by across-channel processes; the greater the number of channels involved, the larger are the effects.

2.3. MDI and perceptual grouping

In everyday life we often listen to several sound sources simultaneously. The auditory system is faced with the task of deciding which "elements" of the complex mixture arise from one source, and which from another. The process of doing this is often called "perceptual grouping" or "stream formation" [2]. The elements of the sound are grouped across-frequency and across time to form percepts of coherent streams each with its own loudness, pitch, timbre and location. Some researchers have suggested that MDI arises from a form of perceptual grouping of the target and the flankers; this presumably reflects a central process. When the target and flankers are perceptually grouped, it may be difficult to discriminate changes in the modulation of the target.

One principle that operates in perceptual grouping is "common fate"; components of a complex sound that change in a similar way over time tend to be grouped together and perceived as a single sound source. Two applications of this principle are relevant to MDI: elements that start and stop together tend to be perceived as a single sound; and elements that are amplitude modulated in a similar way tend to be perceived as a single sound. Several studies have examined the influence of these factors — similarity of amplitude modulation and synchrony versus asynchrony of onsets — on MDI [11, 19].

Figure 2 (data from the same experiment of Moore and Jorasz [12]) shows a small but significant effect on MDI of whether the flankers were comodulated or non- comodulated (open or filled bars respectively) with the target; comodulated flankers usually gave greater interference, hence the greater amount of MDI. This effect was present when the amount of MDI was small (conditions $1-7$). The lack of an effect for larger amounts of MDI might have been produced by a ceiling effect (the change in modulation index at threshold was close to the maximum possible value). Overall, the results suggest that similarity of modulation pattern does play a role in MDI, supporting that idea that central perceptual grouping processes play a role.

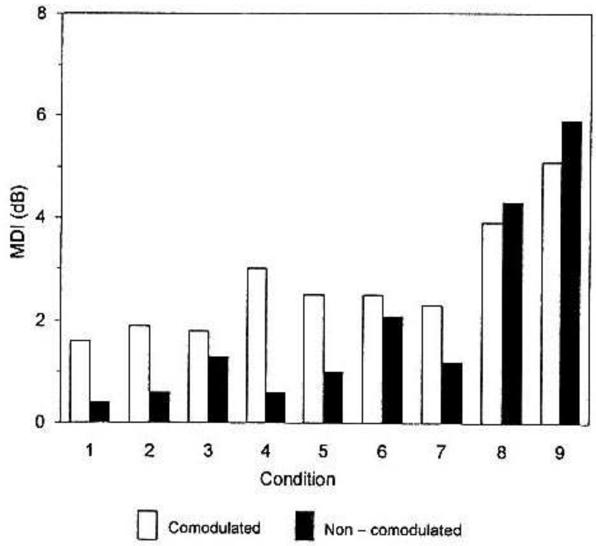

Fig. 2. The influence of comodulation of flankers on the amount of MDI. Conditions and the rest of data as Fig. 1 (from [12]).

Onset asynchrony is known to be a powerful factor in perceptual grouping; when a background sound has been on for some time, an added new sound seems to "pop out" and to be perceived as a separate sound [2, 9]. Thus, if MDI depends on perceptual grouping of the target and flankers, asynchrony of the target relative to the flankers should result in a decrease in MDI. Moore and Jorasz [11] demonstrated that the amount of MDI was indeed markedly reduced by gating the target on after the flankers, a result which has also been found by others [3, 14].

3. Evidence for within-channel processes

So far we have argued that MDI and CMR are at least partly caused by central across-channel processes. There is, however, some evidence suggesting that within-channel processes influence both effects in some circumstances. The peripheral processes involve the flankers either masking part of the excitation pattern of the target or introducing extra modulation into part of the excitation pattern evoked by the target. This might be particularly important for flankers higher in frequency than the target, since changes in excitation level of the target are effectively magnified on the high-frequency side of the excitation pattern [20].

Consider the results shown in Fig. 1. There is a tendency for the amount of MDI to be greater for flankers centred above the target frequency (conditions 4 – 6) than for flankers centred below the target frequency (conditions 1 – 3). This is consistent with a role for within-channel processes. In addition, some studies have shown that the amount of MDI increases as the difference between the target and flankers carrier frequencies decreases [5, 11, 19]. This has been attributed partially to within-channel processes.

Richardson *et al.* [16] studied MDI for users of cochlear implants. They found that thresholds for detecting amplitude modulation of signals applied to a single electrode were influenced by a masking modulation on a second electrode. In other words, a form of MDI occurred. For three of the four subjects, MDI increased with decreases in the spatial separation between the two electrodes. This presumably reflected an increasing overlap of the neural populations excited by the two electrodes.

In Fig. 1 we can see that CMR tends to be greater for multiple flankers centred below than above the target frequency. A possible explanation for this effect is as follows. To obtain maximum CMR, the coding of the target modulation may be more important than the coding of the modulation of any single flanker (provided that multiple flankers are present, to allow for some redundancy in the coding of the modulation of the flankers). When the flankers are all below the target frequency, the changes in excitation level produced by the target would be effectively magnified on the high-frequency side of the excitation pattern, and these magnified changes would not be affected by the flankers. This would lead to greater CMR than when the flankers are all above the target frequency. The effect in this case depends on both peripheral and central processes.

Moore [8] has argued that CMR arises mainly from comparisons of the outputs of different auditory filters, but that these comparisons are made most effectively for filters that are reasonably closely spaced in centre frequency. If this is the case, it reflects an influence of peripheral processes on the central processes that lie at the heart of CMR.

4. Conclusions

It seems likely that MDI and CMR can be influenced both by peripheral within-channel processes and by central across-channel processes. The nature of these processes, and the way that they interact can be explored using relatively simple studies of the detection and discrimination of modulated sounds. We suggest that studies of MDI and CMR can be useful in clarifying the role of peripheral and central processes in hearing.

Acknowledgements

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