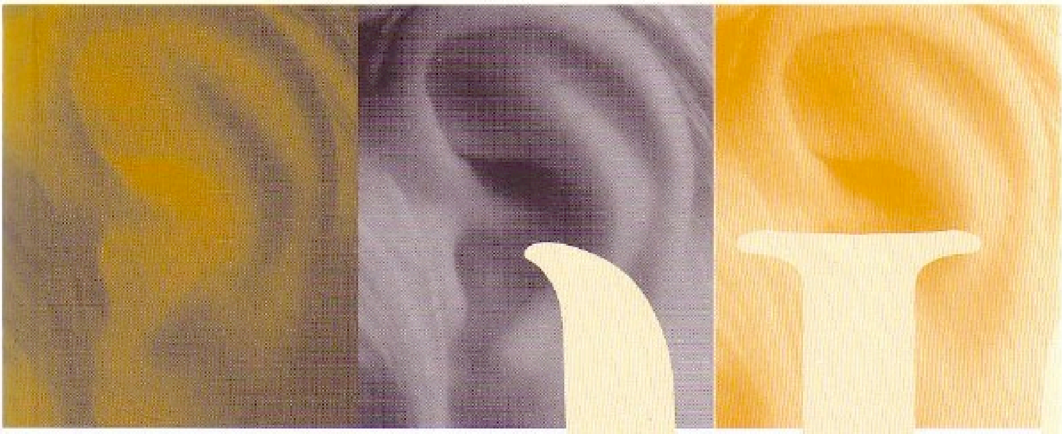
EDITION

# AN INTRODUCTION TO THE
# PSYCHOLOGY OF HEARING



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3. The signal falls well within the frequency range of the background; threshold tends to rise when the signal is at the edge of the frequency range of the background.
4. The level of the signal component is similar to or slightly above the levels of the components in the background.
5. The background is composed of components with equal levels rather than levels which differ from component to component.

The first two aspects of profile analysis described above resemble CMR; recall that CMR is larger when the masker covers a wide frequency range or when several flanking bands are used. Indeed, profile analysis may be regarded as a special case of CMR, where the masker fluctuates randomly in level across stimuli but not within stimuli.

In one sense we should not find the phenomenon of profile analysis surprising. It has been known for many years that one of the main factors determining the timbre or quality of a sound is its spectral shape; this is discussed in more detail in Chapter 7. Our everyday experience tells us that we can recognize and distinguish familiar sounds, such as the different vowels, regardless of the levels of those sounds. When we do this, we are distinguishing different spectral shapes in the face of variations in overall level. This is functionally the same as profile analysis. The experiments on profile analysis can be regarded as a way of quantifying the limits of our ability to distinguish changes in spectral shape.

## 8 NON-SIMULTANEOUS MASKING

'Simultaneous masking' is the term used to describe situations where the masker is present throughout the presentation time of the signal. Time effects in masking have also been studied fairly intensively. Short signals, often called 'probes' are presented at various times in relation to the masker. Two basic types of non-simultaneous masking can be distinguished: (1) backward masking, in which the probe precedes the masker (also known as pre-stimulatory masking); and (2) forward masking, in which the probe follows the masker (also known as post-stimulatory masking). Forward masking is just one of three conceptually distinct processes which may affect the threshold of a probe presented after another sound; the other two are adaptation and fatigue, which were discussed in Chapter 2. Forward masking is distinguished from adaptation and fatigue primarily by the fact that it occurs for maskers which are relatively short in duration (typically a few hundred milliseconds) and it is limited to signals which occur within about 200 ms after the cessation of the masker.

Although many studies of backward masking have been published, the phenomenon is poorly understood. The amount of backward masking obtained depends strongly on how much practice the subjects have received and practised subjects often show little or no backward masking (Miyazaki and Sasaki, 1984; Oxenham and Moore, 1994). The larger masking effects found for unpractised subjects may reflect some sort of 'confusion' of the signal with the masker. In the paragraphs which follow, we will concentrate primarily on forward masking, which can be substantial even in highly practised subjects. The main properties of forward masking are as follows:

1. Forward masking is greater the nearer in time to the masker that the signal occurs. This is illustrated in the left panel of Fig. 3.17. When the delay $D$ of the signal after the end of the masker is plotted on a logarithmic scale, the data fall roughly on a straight line. In other words, the amount of forward masking, in dB, is a linear function of $\log(D)$.

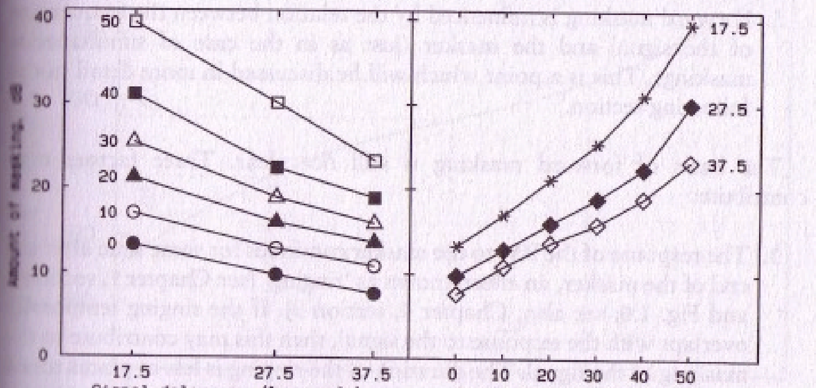

FIG. 3.17 The left panel shows the amount of forward masking of a brief 4-kHz signal, plotted as a function of the time delay of the signal after the end of the noise masker. Each curve shows results for a different noise spectrum level (10–50 dB). The results for each spectrum level fall roughly on a straight line when the signal delay is plotted on a logarithmic scale, as here. The right panel shows the same thresholds plotted as a function of masker spectrum level. Each curve shows results for a different signal delay time (17.5, 27.5 or 37.5 ms). Note that the slopes of these growth of masking functions decrease with increasing signal delay. Adapted from Moore and Glasberg (1983a).

2. The rate of recovery from forward masking is greater for higher masker levels. Regardless of the initial amount of forward masking, the masking decays to zero after 100–200 ms.
3. Increments in masker level do not produce equal increments in amount of forward masking. For example, if the masker level is increased by 10 dB, the masked threshold may only increase by 3 dB. This contrasts with simultaneous masking, where, at least for wideband maskers, threshold usually corresponds to a constant signal-to-masker ratio. This effect can be quantified by plotting the signal threshold as a function of the masker level. The resulting function is called a growth of masking function. Several such functions are shown in the right panel of Fig. 3.17. In simultaneous masking such functions would have slopes close to one. In forward masking the slopes are less than one and the slopes decrease as the value of *D* increases.
4. The amount of forward masking increases with increasing masker duration for durations up to at least 20 ms. The results for greater masker durations vary somewhat across studies. Some studies show an effect of masker duration for durations up to 200 ms (Kidd and Feth, 1982; Zwicker, 1984), while others show little effect for durations beyond 50 ms (Fastl, 1976).
5. Forward masking is influenced by the relation between the frequencies of the signal and the masker (just as in the case of simultaneous masking). This is a point which will be discussed in more detail in the following section.

The basis of forward masking is still not clear. Three factors may contribute:

1. The response of the BM to the masker continues for some time after the end of the masker, an effect known as 'ringing' (see Chapter 1, section 4 and Fig. 1.6; see also, Chapter 4, section 3). If the ringing temporally overlaps with the response to the signal, then this may contribute to the masking of the signal. The duration of the ringing is less at places tuned to high frequencies, where the filters have large bandwidths. Hence, ringing plays a significant role only at low frequencies (Duifhuis, 1971, 1973; Plack and Moore, 1990).
2. The masker produces short-term adaptation or fatigue in the auditory nerve or at higher centres in the auditory system, which reduces the response to a signal presented just after the end of the masker (Smith, 1977). However, the effect in the auditory nerve appears to be too small to account for the forward masking observed behaviourally (Turner *et al.*, 1994).

3. The neural activity evoked by the masker persists at some level in the auditory system higher than the auditory nerve and this persisting activity masks the signal. A model of temporal resolution based on this idea is presented in Chapter 4.

Oxenham and Moore (1995a) have suggested that the shallow slopes of the growth of masking functions shown in the right panel of Fig. 3.17 can be explained, at least qualitatively, in terms of the compressive input-output function of the BM (see Chapter 1, section 5B and Figs. 1.11 and 2.13). Such an input-output function is shown schematically in Fig. 3.18. It has a shallow slope for medium input levels, but a steeper slope at very low input levels. Assume that, for a given time delay of the signal relative to the masker, the response evoked by the signal at threshold is directly proportional to the response evoked by the masker. Assume, as an example, that a masker with a level of 50 dB produces a signal threshold of 12 dB. Consider now what happens when the masker level is increased by 20 dB. The increase in masker

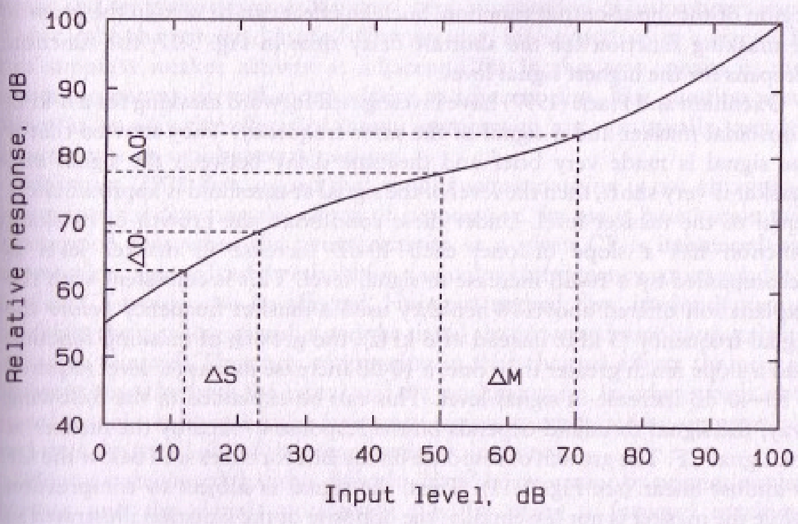

**FIG. 3.18** Illustration of why growth of masking functions in forward masking usually have shallow slopes. The solid curve shows a schematic input–output function on the basilar membrane (BM). The relative response is plotted on a dB scale with an arbitrary origin. When the masker is increased in level by ΔM, this produces an increase in response of ΔO. To restore signal threshold, the response to the signal also has to be increased by ΔO. This requires an increase in signal level, ΔS, which is markedly smaller than ΔM.

lenoted by $\Delta M$ in Fig. 3.18, produces a relatively small increase in
se, $\Delta O$. To restore the signal to threshold, the signal has to be
ed in level so that the response to it increases by $\Delta O$. However, this
s a relatively small increase in signal level, $\Delta S$, as the signal level falls
range where the input-output function is relatively steep. Thus, the
of masking function has a shallow slope.

ording to this explanation, the shallow slope arises from the fact that
al level is lower than the masker level, so the masker is subject to more
ession than the signal. The input-output function has a slope which
ses progressively with increasing level over the range 0 to about 50 dB.
the slope of the growth-of masking function should decrease with
ing difference in level between the masker and signal. This can account
progressive decrease in the slopes of the growth of masking functions
creasing time delay between the signal and masker (see the right-hand
of Fig. 3.17); longer time delays are associated with greater differences
l between the signal and masker. A prediction of this explanation is
e growth of masking function for a given signal time delay should
e in slope if the signal level is high enough to fall in the compressive
of the input-output function. Such an effect can be seen in the growth
sking function for the shortest delay time in Fig. 3.17; the function
s for the highest signal level.

nham and Plack (1997) have investigated forward masking for a 6-kHz
idal masker and a signal of the same frequency. They showed that if
nal is made very brief and the time delay between the signal and
r is very short, then the level of the signal at threshold is approximately
to the masker level. Under these conditions, the growth of masking
n has a slope of one; each 10-dB increase in masker level is
panied by a 10-dB increase in signal level. This is consistent with the
ation offered above. When they used a masker frequency *below* the
frequency (3 kHz instead of 6 kHz), the growth of masking function
slope much greater than one; a 10-dB increase in masker level required
0 dB increase in signal level. This can be explained in the following
he signal threshold depends on the response evoked by the masker at
nal CF. The growth of response on the BM for tones well below the CF
ost linear (see Fig. 1.11). Thus, the signal is subject to compression
the masker is not (essentially, the opposite of the situation illustrated in
18). This gives rise to the steep growth of masking function.

summary, the processes underlying forward masking are not fully
stood. Contributions from a number of different sources may be
tant. Temporal overlap of patterns of vibration on the BM may be
tant, especially for small delay times between the signal and masker.
term adaptation or fatigue in the auditory nerve may also play a role.

At higher neural levels, a persistence of the excitation evoked by the masker may occur. The form of the growth of masking functions on the BM can be explained, at least qualitatively, in terms of the nonlinear input-output functions observed on the BM.

## 9 EVIDENCE FOR LATERAL SUPPRESSION FROM NON-SIMULTANEOUS MASKING

The results from experiments on simultaneous masking can generally be explained quite well on the assumption that the peripheral auditory system contains a bank of overlapping bandpass filters which are approximately linear. However, measurements from single neurones in the auditory nerve show significant nonlinearities. In particular, the response to a tone of a given frequency can sometimes be suppressed by a tone with a different frequency, giving the phenomenon known as two-tone suppression (see Chapter 1, section 6F and Fig. 1.20). For other complex signals, similar phenomena occur and are given the general name lateral suppression or just suppression. This can be characterized in the following way. Strong activity at a given CF can suppress weaker activity at adjacent CFs. In this way, peaks in the excitation pattern are enhanced relative to adjacent dips. The question now arises as to why the effects of lateral suppression are not usually seen in experiments on simultaneous masking.

Houtgast (1972) has argued that simultaneous masking is not an appropriate tool for detecting the effects of suppression. Its use is based upon the assumption that when the neural activity at a given CF is influenced by suppression, the masked threshold for a signal with frequency corresponding to that CF would also be affected. Houtgast argued that, in simultaneous masking, the masking stimulus and the signal are processed simultaneously in the same channel. Thus any suppression in that channel affects the neural activity caused by both the signal and the masking noise. In other words, the signal-to-noise ratio in a given frequency region is unaffected by suppression and thus the threshold of the signal remains unaltered.

Houtgast suggested that this difficulty could be overcome by presenting the masker and the signal successively (i.e. by using a forward masking technique). If suppression does occur, then its effects will be seen in forward masking provided: (1) in the chain of levels of neural processing the level at which the suppression occurs is not later than the level at which most of the forward masking effect arises; (2) the suppression built up by the masker has decayed by the time that the signal is presented (otherwise the problems described for simultaneous masking will be encountered).