On the perception of sinusoidally amplitude modulated signals and its relevance to listening in noise
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Citation for published version (APA):
Koopman, J. (2004). On the perception of sinusoidally amplitude modulated signals and its relevance to listening in noise
Chapter 8

Masking release for speech related to adaptation to SAM*

Abstract

Modulation detection thresholds were measured for a 1 kHz pure tone preceded by a 1 kHz adaptor that was either non-modulated or fully modulated. The duration of the signals was 625 ms and the inter-stimulus intervals varied between 10 and 625 ms. Signals were amplitude modulated by an 8 Hz sinusoid. Ten normal hearing and twelve hearing-impaired subjects participated in the experiments. Clear differences in sensitivity to SAM were found for hearing-impaired listeners when a modulated adaptor rather than a non-modulated adaptor preceded the target. This indicated that hearing-impaired subjects also show modulation detection interference for non-simultaneous signals. The adaptation effect observed correlated strongly with the release of masking for speech when a fluctuating background noise was used instead of a continuous noise with the same long-term RMS levels.

*submitted to the Journal of the Acoustical Society of America
8.1 Motivation

Chapter 6 describes matching experiments carried out for normal hearing and hearing-impaired subjects. When matching the modulation depth to a reference depth, hearing-impaired subjects tended to adjust the modulation depth of the target to be higher than the modulation depth of the reference. Normal hearing subjects do not tend to demonstrate this tendency. In the Discussion of that Chapter, it was suggested that this could be attributed to some kind of adaptation to SAM. The literature described adaptation to SAM for pre-exposure times of several seconds but not for relatively short adaptation periods as used in Chapter 6 (see also section 4.8). The importance of the temporal envelope for speech perception was discussed extensively in Chapter 7. One might expect that the reduced masking release for speech for hearing-impaired subjects may, in some way, be limited by the increased adaptation to SAM. More explicitly, the inability of hearing-impaired subjects to improve speech intelligibility when speech is presented in a fluctuating rather than a continuous noise with the same RMS-level may be caused by the adaptation to fluctuations in the modulated noise.

This paper describes three experiments. The first experiment measured the sensitivity to SAM of a stimulus without an adaptor. The second experiment measured the sensitivity to SAM of a stimulus preceded by a modulated or non-modulated masker. The third experiment measures the masking release for speech using continuous and fluctuating background noises. The relationship between the sensitivity to SAM and masking release for speech will be examined.

8.2 Methods

8.2.1 Subjects

Ten normal hearing and twelve hearing-impaired subjects participated in this study. The normal hearing subjects had thresholds smaller than 15 dB HL at the standard audiometric frequencies from 125 Hz to 8 kHz (re. ANSI 1996). The average age was 29 years and subjects were tested at a randomly assigned ear. Table 8.1 represents the age, tested ear and the auditory thresholds of the hearing-impaired subjects. The bottom row of Table 8.1 represents the average age and thresholds of the hearing
impaired subjects, with their standard deviations. The subject number increases with the average loss at the frequencies 1, 2, and 4 kHz. The best ear was tested in case of an asymmetrical hearing loss.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age</th>
<th>Ear</th>
<th>0.25 kHz</th>
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<th>2 kHz</th>
<th>4 kHz</th>
<th>8 kHz</th>
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<td>36</td>
<td>41</td>
<td>46</td>
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<td>10</td>
<td>9</td>
<td>12</td>
<td>12</td>
<td>22</td>
<td></td>
</tr>
</tbody>
</table>

Table 8.1: *Age, ear measured and pure tone hearing loss of each hearing-impaired subject.*

### 8.2.2 Stimuli

**Non-speech stimuli**

The sensitivity to the SAM of a target signal was measured with and without a preceding stimulus to adapt to (adaptor). All stimuli were fully modulated (m=1) or non-modulated (m=0) sinusoids with a carrier frequency of 1 kHz and a fixed duration of 625 ms gated by a cosine-squared window with 5 ms rise/fall times. Where an adaptor was used, the inter-stimulus interval (ISI) was equal to 10, 62.125, 200, or 625 ms. Each new stimulus was presented at least 1.5 seconds after the previous one and depended on the decision time of the subject. If the adaptor signal was modulated, a sinusoidal amplitude modulation of 8 Hz was applied starting at
maximal amplitude (starting-phase of 90 degrees). The signals were presented at 25
dB SL for all subjects. In addition, extra tests were conducted for normal hearing
subjects at 50 dB SL to approach equivalent sound pressure levels of the experiments
for hearing-impaired subjects (the average hearing loss was 41 dB HL). Stimuli were
scaled back to equal RMS.

Speech stimuli

Speech intelligibility was determined using the VU98 sentences spoken by a female
speaker (Versfeld et al., 2000). Speech intelligibility was determined in a continuous
and in a fluctuating background noise, both having the long-term averaged spectrum
of the female speaker. The fluctuating background noise was produced as described
by Festen and Plomp (1990). Briefly, speech without pauses is split into two bands
(cut-off frequency 1 kHz). The original fine structure is replaced by noise with the
same long-term spectrum as speech. This resulted in a noise with a fluctuating
behavior similar to speech. Speech was presented at 65 dBA, unless the averaged
hearing loss for 500 Hz, 1 kHz and 2 kHz was larger than 40 dB, in which case the
speech was presented at 20 dB above the average hearing loss.

8.2.3 Procedure

The following experiments were conducted in a sound-attenuating booth.

Measurement of absolute thresholds

The audibility of a 1 kHz signal was determined using a 11-2AFC experiment. The
interval was indicated using visual cues. Subjects were asked to indicate whether
they heard the signal. The signal level was decreased by 4 dB after three successive
correct responses and increased by 4 dB after one incorrect response, according to
a 1-up 3-down rule, tracking down the 79.1 % point of convergence (Levitt, 1971).
After two reversals, the step size was reduced to 2 dB. The threshold was determined
by taking the average of the last 6 of 10 reversals. Measurements were carried out
twice. When test and retest deviated by more than 3 dB, a third test was carried
out. Visual feedback was given for 300 ms after each response.
Sensitivity to the modulation depth of SAM signals

The sensitivity to a SAM signal was determined using a 11-2AFC procedure. The modulation depth of the target was decreased by 4 dB \((20 \log_{10}[\text{in}])\) after three successive correct responses and increased by 4 dB after one incorrect response. After two reversals, the step size was reduced to 2 dB. Hence, the level of 79.1 % correct responses on the psychometric curve is determined. The threshold was determined by taking the average of the last 6, of 10, reversals. Measurements were carried out twice. When test and retest deviated by more than 3 dB a third test was carried out. Visual feedback was given for 300 ms after each response.

Speech intelligibility

Speech intelligibility was measured using a standard speech reception threshold (SRT) test (Plomp and Mimpen, 1979) that determines the speech-to-noise ratio corresponding to 50% correct responses for short meaningful redundant sentences. The sentences (VU98: Versfeld et al., 2000) were presented in a continuous and a fluctuating noise, both with the same long-term averaged noise spectrum as the sentences. When each word in the sentence was (orally) repeated correctly, the speech level was decreased by 2 dB. An incorrectly repeated sentence resulted in a 2 dB higher speech level. The first of 13 sentences was repeated until the subject repeated it correctly, using 4 dB steps in order to quickly converge to 50% intelligibility. Speech intelligibility was estimated by averaging the S/N ratio of the last 9 sentences in noise and the estimated S/N ratio of the sentence following the last sentence. Measurements were carried out twice. When test and retest deviated by more than 2 dB a third test was conducted.

8.2.4 Apparatus

Speech stimuli were reproduced using a compact disc and digitized at a 44.1 kHz sampling rate. The non-speech stimuli were digitally generated at a sampling rate of 16 kHz using a Tucker-Davis Technology (TDT-II) system. Speech and non-speech stimuli were presented via a 16-bit DA-converter (DA3-2) and an anti-aliasing filter (FT6: cut-off frequency 8 kHz). Presentation levels were controlled using programmable attenuators (PA4) and in the case of speech intelligibility, speech
and noise were summed using a summer (SM3). These signals passed a headphone buffer (HB6) before being presented to the subjects via headphones (Telephonics TDH 39-P).

8.3 Results

8.3.1 Experiment 1: Sensitivity to SAM

The accuracy obtained in assessing the sensitivity to SAM is high (Cronbach’s $\alpha = 0.93$). According to a paired $t$-test, there is no significant learning effect (LME, $p$-value = 0.37).

<table>
<thead>
<tr>
<th>Group</th>
<th>No adap. (exp. 1)</th>
<th>Unmod. adapt. (exp. 2)</th>
<th>Mod. adapt. (exp. 2)</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH(25 dB SL)</td>
<td>-17.2 ± 2.8</td>
<td>-17.5 ± 2.6</td>
<td>-15.9 ± 2.8</td>
<td>1.6 ± 1.8</td>
</tr>
<tr>
<td>NH(50 dB SL)</td>
<td>-21.9 ± 3.6</td>
<td>-22.3 ± 3.4</td>
<td>-20.3 ± 4.6</td>
<td>2.0 ± 2.3</td>
</tr>
<tr>
<td>HI(25 dB SL)</td>
<td>-21.5 ± 3.3</td>
<td>-20.4 ± 4.4</td>
<td>-15.9 ± 5.5</td>
<td>4.4 ± 3.5</td>
</tr>
</tbody>
</table>

Table 8.2: Sensitivity to SAM (in dB) for the three groups. The results for experiment 1 are given in the first column, the results of experiment 2 in the last three columns.

The sensitivity to SAM for normal hearing subjects increased significantly by 4.7 dB (see first column Table 8.2) when the sensation level (SL) is increased from 25 dB SL to 50 dB SL (LME, $p$-value < 0.01). This is in agreement with Kohlrausch et al. (2000). At equal SL, hearing-impaired subjects are significantly more sensitive to SAM than normal hearing subjects (5.3 dB; $p$-value < 0.01), whereas when comparisons are carried out at roughly equal SPL-levels, sensitivity is not significantly different (LME, $p$-value = 0.67).

8.3.2 Experiment 2: Sensitivity to SAM when preceded by an adaptor

The accuracy of the SAM thresholds preceded by an adaptor is high (Cronbach’s $\alpha = 0.96$). According to a paired $t$-test, there is no significant learning effect ($p$-value = 0.17).
8.3. Results

Table 8.3: Results for the linear mixed effects models. The effect of presentation level for normal hearing subjects is given by the first column. The effect of normal hearing and hearing-impaired subjects tested at equal SL and comparable SPL is given in the second and third column, respectively. The effect-size is given in dB for the main effects. Asterisks denote the level of significance (* p-value < 0.05; ** p-value < 0.01) The modulation depth of the adaptor is given by ml. The effect of the inter-stimulus interval by ISI. n.a. stands for not applicable.

Results in Table 8.3 were determined by averaging over subjects and ISIs. The results in Table 8.3 indicate that normal hearing subjects are less sensitive to SAM at 25 dB SL than at 50 dB SL when the target was preceded by an adaptor averaged over ISIs (LME, p-value < 0.0001: 4.6 dB). The sensitivity to SAM is independent of presentation level, not significantly different for normal hearing and hearing-impaired subjects (LME main effect, p-value = 0.35 and p-value = 0.09: for 25 SL and at comparable SPLs, respectively). The sensitivity to SAM of the target preceded by a non-modulated adaptor is significantly higher than when the target was preceded by a modulated adaptor (LME, p-value < 0.001). When hearing-impaired and normal hearing subjects were compared using a modulated adaptor and at equal SL, the sensitivity to SAM of the two groups was approximately equal. However, if normal hearing and hearing-impaired subjects are compared at comparable SPLs, the sensitivity to SAM is slightly higher than the sensitivity of hearing-impaired for a non-modulated adaptor. Averages are given in the last three columns of Table 8.2.
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Since the results differed greatly between subjects, individual results are given in Figures 8.1, 8.2, and 8.3. The horizontal lines indicate the sensitivity to SAM without an adaptor (Exp. 1). Figure 8.1 gives the results for 10 normal hearing subjects, measured at 25 dB SL. Generally, the sensitivity to SAM preceded by a modulated (plus symbols) or by an non-modulated (circles) adaptor is comparable to the sensitivity to SAM without an adapting stimulus (paired t-test: p-value > 0.1). For relatively short ISIs, the sensitivity to SAM preceded by a non-modulated adaptor is higher than the sensitivity to SAM when preceded by a modulated adaptor (paired t-tests, p-value < 0.01; ISI=10.62 ms). Three subjects, NH2, NH3 and NH10, deviate from this general trend. For these subjects, particularly NH3, the sensitivity to the SAM of a target is clearly decreased over the whole range of ISIs when a modulated adaptor is present.

Data obtained for normal hearing subjects at 50 dB SL are given in 8.2. The sensitivity to SAM with a non-modulated adaptor (circles) is generally comparable to the sensitivity to SAM without an adaptor (straight line) (paired t-test, p-value = 0.07). In addition, the sensitivity to SAM is often lower when a modulated adaptor (plus symbols) was used instead of a non-modulated adaptor (circles) for all ISIs (paired t-test, p-value < 0.01; except for 125 ms p-value = 0.45). NH3 also deviates from the other subjects. There the sensitivity to SAM for NH3 is clearly higher when a non-modulated instead of a modulated adaptor precedes the target.

Figure 8.3 shows that for most hearing-impaired subjects, the sensitivity to SAM without an adaptor is generally similar to SAM when a non-modulated adaptor preceded the target (paired t-tests, p-value > 0.04). The sensitivity to SAM without an adaptor is significantly higher than the sensitivity to SAM when preceded by a modulated adaptor (paired t-tests, p-value < 0.005 for all ISIs). All hearing-impaired subjects, except for HI2, whose results were inconsistent, showed a clearly reduced sensitivity to SAM when the target was preceded by a modulated rather than a non-modulated stimulus. Figure 8.3 also indicates that the individual hearing-impaired subjects react differently to the adaptation stimulus. For instance, HI6 shows an enormous reduction in the sensitivity to SAM when the adaptor was modulated instead of non-modulated. Whereas the sensitivity to SAM for other hearing-impaired subjects, such as HI8 and HI5, is barely affected by the modulated adaptor.
8.3. Results

Figure 8.1: Individual results for the normal hearing subjects measured at 25 dB SL. Sensitivity to SAM (ordinate) is given as a function of the inter stimuli interval in ms (abscissa). The solid horizontal line indicates the sensitivity to SAM without an adaptor (Exp. 1), circles and plus symbols show the sensitivity to SAM when a non-modulated or a modulated adaptor precedes the target, respectively. Subject numbers are given in the right-upper corner.
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Figure 8.2: Similar to Figure 8.1 for normal hearing subjects measured at 50 dB SL.
8.3. Results

Figure 8.3: Similar to Figure 8.1 for hearing impaired subjects.
8.3.3 Experiment 3: Masking release for speech

The accuracy of measurements is very high. Cronbach’s $\alpha$ equals 0.98. According to a paired $t$-test, there were no significant learning effect ($p$-value = 0.91).

The signal-to-noise ratio at which 50% of the sentences were intelligible is significantly lower for normal hearing subjects than for hearing-impaired subjects (LME, $p$-value < 0.001: 4.5 dB). The interaction between hearing capacity and the type of noise used is significant (LME, $p$-value < 0.001). For hearing-impaired subjects, the SRT in a continuous background noise is comparable to the SRT in a fluctuating background noise. For normal hearing subjects, speech intelligibility is significantly better in a fluctuating noise than in a continuous background noise ($p$-value < 0.001: 4.0 dB). Figure 8.4 shows a scatter plot of the S/N ratios obtained in a continuous background noise (abscissa) and in a fluctuating background noise (ordinate). The horizontal lines indicate the average speech intelligibility in a fluctuating background noise for normal hearing (dashed) and hearing-impaired subjects (solid); the vertical lines indicate the averaged intelligibility of speech in a continuous background noise. The difference in intelligibility between normal and hearing-impaired listeners (distance between the two lines) is clearly larger for the speech presented in a fluctuating noise than in a continuous noise. The sloping line indicates the values where the SRT in fluctuating noise is equal to the SRT in a continuous background noise. The results are comparable to the data for normal hearing and hearing-impaired subjects as reported by Versfeld and Dreschler (2002) indicating that the SRT-values in continuous noise are comparable to the SRT-values in a fluctuating noise unless the SRT in continuous noise is approximately lower than -2 dB. In this case, the SRT in fluctuating noise is better than the SRT in continuous noise.
Figure 8.4: *Individual speech intelligibility data. Speech intelligibility obtained in a continuous background noise (abscissa) versus speech intelligibility in a fluctuating background noise (ordinate). The horizontal lines indicate the average S/N ratios for a fluctuating background noise for normal hearing (dashed) and hearing impaired subjects (solid); the vertical lines indicate the average S/N ratios in a continuous background noise.*
8.4 Discussion

8.4.1 Adaptation to SAM

Adaptation to SAM has been observed in psychophysical (Regan and Tansley, 1979; Tansley and Suffield, 1983; Wojtczak and Viemeister, 2003) and physiological (Mäkelä et al., 1987; Coombs and Fay, 1985) experiments for relatively long exposure times to SAM. Using modulation matching after 10 minutes of pre-exposure to SAM (m=0 dB), indicated that the perceived modulation depth for normal hearing subjects was reduced for signals modulated by the same rate using modulation depths of -4, -6, and -8 dB. The amount of adaptation measured by this matching paradigm was similar to the amount reported for modulation detection after pre-exposure to SAM (Wojtczak and Viemeister, 2003). The study described in this chapter shows that subjects, particularly those with impaired hearing, are less sensitive to SAM when it is preceded by a modulated signal, even when the duration of the adaptor was as short as 625 ms. This suggests that modulation detection interference applies to both simultaneous and non-simultaneous presentation of target and modulated masker.

The results in this chapter indicate that subjects, who are more sensitive to SAM, are also more sensitive to SAM preceded by a non-modulated or another SAM signal. This has been expressed in the correlations between the ability to detect SAM, when it is presented alone and when it is preceded by a non-modulated signal, for both equal SLs (r = 0.866. p-value < 0.001) and comparable SPLs (r = 0.835. p-value < 0.001). Corresponding correlation coefficients for SAM detection preceded by another SAM signal are 0.581 for equal SLs (p-value < 0.01) and 0.777 for comparable SPLs (p-value < 0.01). There is no association between the adaptation effect, defined as the difference in sensitivity to SAM for non-modulated and SAM-modulated adaptors, and the sensitivity to SAM without an adaptor for equal SLs (r = 0.266. p-value > 0.05) or comparable SPLs (r = -0.281. p-value > 0.05). The definition of the adaptation effect may result in overestimation for short ISIs, since the non-modulated signal may have served as a reference, improving SAM detection. An 1-AFC procedure was chosen instead of the more commonly used 2- or 3-AFC procedures. This procedure reduces the possibility of comparing the target with other non-modulated signals in the 2- or 3-AFC tasks for the conditions where
the non-modulated masker precedes the target. For the group of subjects as a whole, there was no difference between the detection of SAM preceded by a non-modulated signal for ISIs of 10 ms and 625 ms (paired t-test, p-value = 0.07), but some subjects clearly benefited from the non-modulated adaptor for short ISIs, meaning that their reduction in sensitivity to SAM may have been overestimated (e.g. HI4, NH1, NH4, and NH5 measured at 25 dB SL and NH1, NH2, NH3, NH7, and NH8 measured at 50 dB SL).

There are three theories in classical psychophysics, which may explain the adaptation effect. Firstly, the human ear may group sounds perceptually. Although modulation detection interference is known to be partly a result of perceptual grouping (Oxenham and Dau, 2001; Bacon et al., 1995; Shailer and Moore, 1993), modulation masking still occurred, reducing the effects known to enhance perceptual grouping, such as rise-fall time differences and similar modulation rates. This implies that, besides the fact that subjects could easily distinguish between the two separate stimuli, perceptual grouping may not have caused these adaptation effects. In addition, when the adaptor is perceived to continue at a modulation rate of 8 Hz, the envelopes of the adaptor and target signals are in phase for ISIs of 125 and 625 ms and out of phase for an ISI of 62 ms. However, there is no significant difference in sensitivity to SAM for ISIs of 62 ms and 125 ms, indicating that the perceptual grouping does not contribute importantly to the adaptation effect.

Secondly, classical forward masking may lead to a reduced sensitivity to SAM, since hearing impaired subjects cannot use the whole signal to detect SAM, as they experienced a slower recovery from forward masking at equal SLs (Glasberg et al., 1987). Since the adaptor and target are presented at the same SL and the ISI are longer than the periods in which forward masking may occur (Duifhuis, 1973), it is unlikely that forward masking causes the adaptation effect.

Thirdly, a loss of compression enhances a modulated envelope, meaning that the adaptation effect may be larger for hearing-impaired subjects. However, since adaptation was defined in terms of the difference between the sensitivity to SAM preceded by a non-modulated and by a modulated adaptor, the target will be subjected to the same compression system in both cases. In addition, a signal cannot be more than fully modulated, which implies that the induced sensation is probably similar.
The results also indicate that the recovery period may last longer than previously thought. The reduction in sensitivity caused by a modulated adaptor with ISIs of 10.62 and 625 ms is not significantly different for the whole group of subjects (paired $t$-tests. $p$-values > 0.1). However, the subgroup of hearing-impaired subjects with a large adaptation effect (>3 dB) became more sensitive to SAM for increasing ISI. Exposure times of 20 minutes may require recovery periods of almost 1 minute (Tansley and Suffield, 1983), suggesting that adaptation effects observed in periods of up to 625 ms are not particularly unusual.

The results presented in this chapter indicate that hearing-impaired subjects need longer to process the modulation of an adaptor. They were presented with a modulated target, while their auditory system was still analyzing the first signal. They are only able to detect AM if the modulation depth is larger than that of the remainder of the ‘after image’ of the adaptor. Physiologically, these results can be interpreted as indicating that hearing-impaired subjects’ SAM-filters (as suggested by Millman et al., 2002) recover more slowly, adapt more quickly, or do both. Psychophysically, the analysis window of the hearing impaired ear may be inadequate.

### 8.4.2 The relationship between release of masking for speech and the sensitivity to SAM

The sensitivity to SAM is a measure of temporal resolution and determines the accuracy, by which the envelope of a signal can be detected. Since the envelope is very important to the intelligibility of speech, the sensitivity to SAM may correlate with speech intelligibility. However, there seems to be no relationship between speech intelligibility in fluctuating noise and SAM detection without an adaptor at equal SLs ($r = 0.22$, $p$-value = 0.5) or at comparable SPLs ($r = 0.152$, $p$-value > 0.32). The same holds for SAM measurements preceded by an non-modulated or a modulated adaptor ($r < 0.20$; $p$-value > 0.45). Speech intelligibility in a continuous background noise correlates significantly with the sensitivity to SAM without an adaptor measured at equal sensation levels ($r = -0.48$; $p$-value = 0.024). However, the correlation disappears when the SII (ANSI, 1997), instead of the actual SRT, is used. Since the SII incorporates the effect of hearing loss in intelligibility
scores. This indicates that the use of two non-homogeneous subgroups, consisting of normal hearing and hearing-impaired subjects, is the most important factor in the significance of the correlation. In addition, the SRT in continuous noise and the SII do not correlate with the sensitivity to SAM preceded by an adaptor ($r < 0.348$; $p$-value $> 0.11$).

Experiment 2 shows that placing a modulated adaptor before the target reduced the sensitivity to SAM, especially for hearing-impaired subjects. Experiment 3 clearly indicates that normal hearing subjects experience better speech intelligibility in the fluctuating noise than in the continuous noise, whereas this is often not true for hearing-impaired subjects (the first two rows of Table 8.4). Figure 8.5 illustrates the results for all subjects for both experiments. The amount of adaptation (abscissa) is largest for hearing-impaired subjects, especially HI6. The amount of masking release for speech (ordinate) is smaller for hearing-impaired subjects, especially HI6 and HI10. Apparently, the masking release for speech reduces when the size of the adaptation effect, at equal SLs averaged over all ISIs (abscissa), increases (i.e. more masking).

In the previous section, it was mentioned that the adaptation effect may have been overestimated since the non-modulated adaptor may have served as a reference. The third and fourth row of Table 8.4 represent the correlation coefficients between the release of masking for speech and the size of the adaptation effect, defined as the difference between the sensitivity to SAM without an adaptor and the sensitivity to SAM preceded by a modulated adaptor. The relationship between this definition of the adaptation effect averaged over all ISIs and the release of masking for speech is illustrated in Figure 8.6. The proportion of variance explained was 0.36 for the original definition of the adaptation effect and 0.50 for the revised definition. The last two rows in Table 8.4 indicate that the correlations based on hearing-impaired subjects alone are reasonably high, implying that the relationships found are not the results only due to the comparison between normal hearing and hearing-impaired subjects.

A lot of studies have examined the relationship between temporal resolution and speech intelligibility. Most studies indicate that speech intelligibility is only marginally dependent on measures of temporal resolution. In an extensive study by Festen and Plomp (1983), significant correlation coefficients were reported between
Table 8.4: Correlation coefficients between the amount of adaptation and the release of masking for speech. The columns give the ISI at which adaptation is determined. SL and SPL indicates that the normal hearing data were obtained at 25 dB SL and 50 dB SL, respectively. Asterisks denote the level of significance (* p-value < 0.05; ** p-value < 0.01)

<table>
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<th></th>
<th>$ISI_{10,ms}$</th>
<th>$ISI_{62,ms}$</th>
<th>$ISI_{125,ms}$</th>
<th>$ISI_{200,ms}$</th>
<th>$ISI_{625,ms}$</th>
<th>$TSI$</th>
</tr>
</thead>
<tbody>
<tr>
<td>MR (SL) (N=22)</td>
<td>-0.27</td>
<td>-0.51*</td>
<td>-0.48*</td>
<td>-0.60**</td>
<td>-0.42</td>
<td>-0.60**</td>
</tr>
<tr>
<td>MR (SPL) (N=22)</td>
<td>-0.34</td>
<td>-0.57***</td>
<td>-0.34</td>
<td>-0.59**</td>
<td>-0.45*</td>
<td>-0.59**</td>
</tr>
<tr>
<td>MR (SL re. dlm) (N=22)</td>
<td>-0.63**</td>
<td>-0.69**</td>
<td>-0.64**</td>
<td>-0.76**</td>
<td>-0.62**</td>
<td>-0.70**</td>
</tr>
<tr>
<td>MR (SPL re. dlm) (N=22)</td>
<td>-0.55**</td>
<td>-0.63**</td>
<td>-0.52*</td>
<td>-0.68**</td>
<td>-0.52*</td>
<td>-0.65**</td>
</tr>
<tr>
<td>MR (HI) (N=12)</td>
<td>-0.01</td>
<td>-0.75**</td>
<td>-0.09</td>
<td>-0.67*</td>
<td>-0.51</td>
<td>-0.57</td>
</tr>
<tr>
<td>MR (HI) (re. dlm)(N=12)</td>
<td>-0.21</td>
<td>-0.50</td>
<td>-0.43</td>
<td>-0.65*</td>
<td>-0.51</td>
<td>-0.64*</td>
</tr>
</tbody>
</table>

speech intelligibility in noise and spectral measures, but not for temporal measures such as forward masking, backward masking, click thresholds, and click thresholds in noise. This indicates that, spectral properties are more closely related to speech intelligibility in continuous background noise. Takahashi and Bacon (1992) found no significant correlations between modulation detection and the intelligibility of speech in noise. Dreschler and Leenw (1990) found that, from a selection of conditions, only the STI and the minimal detectable gap thresholds for wideband signals correlated significantly. The significant correlations found in the present study suggest that the extent to which subjects can benefit from temporal gaps in the noise is probably more related to measures of temporal resolution, at least for adaptation to SAM, than speech intelligibility in a continuous background noise. When speech is presented in a fluctuating background noise, similar effects may occur as when SAM is preceded by a modulated adaptor. The results suggest that hearing-impaired subjects need more time to process the information in an adaptor or a fluctuation in the background.
Figure 8.5: Scatter plot of the release of masking and the adaptation effect. The difference in sensitivity to SAM preceded by a modulated adaptor and a continuous adaptor is given on the abscissa (averaged over all ISIs). The release of masking for speech in fluctuating noise compared to continuous noise is given on the ordinate.

noise. Similar problems may occur for normal hearing subjects for simultaneous MDI. This may explain why normal hearing and hearing-impaired subjects encounter the same amount of interference (Grose and Hall, 1994). In order to improve SAM detection and speech intelligibility, the modulation depth would have to be increased or the level of noise reduced. This would allow the signal to be processed adequately.
Figure 8.6: As in Figure 8.5, but now the amount of adaptation is determined relative to the situation without a preceding stimulus.
8.5 Conclusions

This study has examined whether the sensitivity to SAM is reduced when a SAM signal is preceded by a modulated signal. The results indicate that:

1. modulation detection interference (MDI) occurs in signals presented simultaneously as well as those presented non-simultaneously.

2. non-simultaneous MDI, or adaptation, appears to occur for all hearing-impaired and some normal hearing subjects.

3. the amount of adaptation correlates strongly with the release of masking for speech. Apparently, the hearing-impaired ear needs longer to recover from pre-exposure to SAM.

4. adaptation of modulation perception may be one of the factors, which prevent hearing-impaired listeners from profiting from the temporal gaps in background noise.