OFF FREQUENCY MASKING FUNCTION AT HIGH LEVELS: A CLINICAL STUDY ON NONLINEAR MASKING FUNCTION AT HIGH LEVELS BY CHANGING THE MIDDLE EAR STIFFNESS

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Abstract- At the highest signal levels, the masking function for the off-frequency condition seems to become more linear. While some basilar membrane data show more linear growth at high levels, others do not. Aim of the present study is to assess function of masking at high levels regarding its clinical appearance. In this experiment we evaluated the hearing thresholds of three different signals (wide-band, low pass filtered, and high pass filtered noises) in presence of a high level low frequency masker (90 dB SPL, 220 Hz), and we decreased the transmission of both masker and signal by changing the middle ear stiffness in 42 normal subjects to determine whether or not their thresholds will change by the same amounts which leads to linear function or their thresholds will change by different amounts which will be related to nonlinear function of masking at high levels. Mean wide-band, low pass filtered, and high pass filtered noises hearing thresholds were better (lower) in +/- 300 daPa air pressure conditions than 0 daPa pressure, and these differences were statistically significant. In conclusion, as the level of the tone was effectively decreased by changing the impedance, frequency tuning improves and the noise was less suppressed by the tone, making it easier to detect. Therefore, at the highest signal levels, the masking function for the off-frequency condition seems to remain nonlinear.
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INTRODUCTIN

Physiological and psychoacoustical studies of cochlear mechanisms have established that the response of the basilar membrane (BM) to tones at characteristic frequency (CF) is generally nonlinear and compressive (1).

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Hearing thresholds increase more rapidly for signal frequencies well above the masker frequency region (off-frequency condition); this leads to the well known “upward spread of masking” (2).

At the highest signal levels, the masking function for the off-frequency condition seems to become more linear. While some BM data show more linear growth at high levels (3) others do not (4). Aim of the present study is to assess function of masking at high levels regarding its clinical appearance. In this experiment we evaluated the hearing thresholds of three signals with different frequency bands in presence of a high level low frequency masker (90 dB SPL, 220 Hz), and we decreased the transmission of both masker and signal by changing the middle ear stiffness to determine whether or not their thresholds will change by the same amounts which leads to linear function or their thresholds will change by different amounts which will be related to nonlinear function of masking at high levels. Changes of atmospheric pressure can increase air conduction (AC) hearing thresholds when they lead to a static pressure difference across the tympanic membrane; increases in threshold occur especially for low frequencies and are probably due to increasing stiffness and damping of the AC sound transmission mechanisms (5-7).

If off-frequency masking at high levels is not linear, then when you increase/decrease the masker level by 10 dB, you will find that the signal threshold increases/decreases by 20 dB or more, but if the off-frequency masking at high levels is linear both of them should increase/decrease by the same amounts. Let us assume this simple relationship in this case, *i.e.*, that there is a 2:1 ratio between masker level and signal level at threshold: In the initial condition, the masker tone is at 90 dB SPL and let us say the noise level at threshold is 20 dB SPL. Let us assume that changing the middle ear impedance leads to a 5 dB reduction in effective level at all frequencies. In other words, as far as the cochlea is concerned, the masker is now at 85 dB SPL and the noise signal is at 15 dB SPL. However, because of the nonlinear nature of the masking, the threshold for the noise signal is reduced by 10 dB (instead of only 5 dB), so that its threshold is now 10 dB SPL. In other words, changing the middle ear impedance has actually reduced the threshold of the noise by 5 dB.

MATERIALS AND METHODS

This study conducted as a quasi-or-non-randomized-clinical trial and sampling procedure was non probability sampling and performed based on availability of subjects. Forty-two subjects who participated in this experiment in the audiology clinic of Taleghani Hospital in Tehran, Iran were male and female normally hearing individuals (aged 20-30 years). Their behavioral thresholds for pure tones were 10 dBHL or better over a frequency range 0.25 to 8 KHz that measured in a sound proof room with a digital clinical audiometer AC3, and TDH 39 headphones. All subjects had un-occluded external ear canals, a healthy tympanic membrane in otoscopic inspection and normal tympanometry. The pump manometer system of the electro acoustic impedance bridge (AZ7 Impedance Audiometer) with TDH-49 head set was used to change the air pressure in the ear canal.

The instruments used, audiometer and tympanometer, were calibrated according to manufacturer specifications by Intracoustic Company representative in Iran-Laboratory Technology Co. Ltd.

This experiment compares thresholds for the signals (Wide band noise, Low pass filtered noise, and high pass filtered noise) with simultaneous high level masker which is centered at a frequency well below that of the signal (off-frequency condition) in different conditions of external ear air pressure.

After insuring a hermetic seal of the probe unit in the ear canal and presenting a probe tone (220 Hz, 90 dB), we measured hearing thresholds of wide-band, low pass filtered, and high pass filtered noises with three different air pressure conditions: +300 daPa, –300 daPa and 0 daPa. Noise thresholds were assessed in dB SPL, through the probe set commonly used for ipsilateral acoustic reflex measurements. These three stimuli threshold values can be filled in at 750, 1000, and 2500 Hz (considering that the limits of the three bands are about 300, 1600, and 4000 Hz). Each patient was instructed to press a hand held button when hearing a noise, otherwise to release it. The modified Hughson-Westlake method was used with stimulus duration of approximately 1.0 s.

After a correct response from the subject the level was decreased by 10 dB and after each failure the level was increased by 5dB. The lowest level with two correct (out of 4 possible) responses was chosen as the noise hearing threshold. Paired *t* tests were used to compare the hearing thresholds of the noises for the different pressure conditions. Statistical analysis was performed with SPSS 10.0. A statistical level of $P < 0.05$ was chosen. Each subject read and signed an informed consent form approved by Shaheed Beheshti University of Medical Sciences' Institutional Review Board on Human Subject Research and this research was conducted in accordance with the Helsinki Declaration in ethical issues (1, 2).

RESULTS

Mean wide-band noise hearing thresholds varied from 13.5dB (SD = 8.15) with 0 daPa up to 9.4 dB (SD = 8.13) at +300 daPa and 8.3 dB (SD = 7.13) at –300 daPa air pressure. Mean threshold for low pass filtered noise varied from 28.6 dB (SD = 10) at 0 daPa up to 17.7 dB (SD = 7.09) at –300 daPa and 17.9 dB (SD = 7.74) at +300 daPa air pressure. The mean high pass filtered noise varied from 12.1dB (SD = 8.78) at 0 daPa to 9.6 dB (SD = 7.92) at +300 daPa, and 8.2 dB (SD = 7.64) at –300 daPa air pressure (Table 1 and Fig. 1).

The results of 9 paired groups which were analyzed by pair *t* test are as follow (Table 2):

Group 1 compares wide-band noise thresholds at 0 and +300 daPa. The 95% confidence interval ranged from 1.7 to 6.4. The difference between them was highly significant ($P \leq 0.001$). Group 2 compares wide-band noise thresholds at 0 and -300 daPa. The 95% confidence interval ranged from 2.1 to 8.1. The difference between them was highly significant ($P \leq 0.001$). Group 3 compares wide-band noise thresholds at +300 and -300 daPa.

The 95% confidence interval ranged from -7.52 to 3.66. The difference between them was not statistically significant. Group 4 compares low-pass filtered noise thresholds at 0 and +300 daPa. The 95% confidence interval ranged from 7.10 to 14.57. The difference between them was highly significant ($P \leq 0.001$). Group 5 compares low-pass filtered noise thresholds at 0 daPa and -300 daPa. The 95% confidence interval ranged from 7.41 to 14.50. The difference between them was highly significant ($P \leq 0.001$). Group 6 compares low pass filtered noise thresholds at +300 daPa and -300 daPa.

Table 1. Hearing threshold levels for wide band noise, low pass filtered noise, and high pass filtered noise in 3 air pressure conditions (0, + 300,-300 daPa) in 42 normal hearing cases*

	0 daPa	+300 daPa	-300 daPa
Wide band noise	13.45±8.15	9.4±8.13	8.33±7.13
Low pass noise	28.6±10	17.9±7.74	17.7±7.09
High pass noise	12.1±8.78	9.6±7.92	8.2±7.6

* Data are given as mean ± SD.

Table 2. The 95% confidence interval for mean difference and result of paired t test in each group

Group	C.I 95% Mean, difference	*t* df.=41	Results of paired *t* test
1	1.7, 6.4	3.5	$P < 0.001$
2	2.1, 8.1	3.4	$P < 0.001$
3	-7.52, 3.66	-0.7	NS.
4	7.10, 14.57	5.8	$P < 0.001$
5	7.41, 14.50	3.1	$P < 0.001$
6	-2.10, 2.34	0.1	NS.
7	-0.13, 5.13	1.9	NS.
8	1.21, 6.65	2.6	$P < 0.006$
9	-0.27, 3.12	1.7	NS.

Abbreviations: CI 95%, the 95% confidence interval; NS, not statistically significant.

The 95% confidence interval ranged from –2.10 to 2.34. The difference between them was not statistically significant. Group 7 compares high pass filtered noise thresholds at 0 daPa and +300 daPa. The 95% confidence interval ranged from –0.13 to 5.13. The difference between them was not statistically significant. Group 8 compares high-pass filtered noise thresholds at 0 daPa and -300 daPa. The 95% confidence interval ranged from 1.21 to 6.65. The difference between them was significant ($P \leq 0.006$). Group 9 compares high-pass filtered noise thresholds at +300 daPa and -300 daPa. The 95% confidence interval ranged from –0.27 to 3.12. The difference between them was not statistically significant.

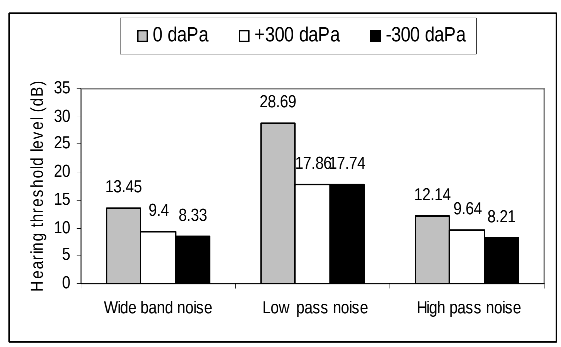

Fig. 1. Means (dB) of hearing threshold levels for wide band noise, low pass filtered noise, and high pass filtered noise in 3 air pressure conditions (0, + 300,-300 daPa) in 42 normal hearing cases.

DISCUSSION

Many physical factors in outer and middle ear change during increasing and decreasing of the air pressure of the ear canal. The changes include sound pressure amplification and resonance frequency of the canal (10,11), acoustical absorption of tympanic membrane (TM) surface, TM motions (12), density and volume of outer and middle ears, and displacement of round window membrane. The aim of this study was to assess nonlinear function of masking at high levels. We evaluated the effect of decreasing the transmission of both masker (loud tone) and signal (noise) by approximately same levels on hearing threshold of the signal. The results showed when stiffness of middle ear increased (according to increasing or decreasing air pressure in the external auditory canal up to ±300 daPa) wide-band noise, low-pass filtered and high-pass filtered noise hearing thresholds become better in comparison with thresholds obtained with normal middle ear pressure; except in pair 7.

It is probably related to the nonlinear growth of masking that is found, especially at high levels, and it can in turn be traced to the broader frequency tuning and increasing suppression found in the cochlea at high levels. In other words, the noise is being detected at a frequency remote from that of the tone. As the level of the tone was effectively decreased by changing the impedance, frequency tuning improves and the noise was less suppressed by the tone, making it easier to detect. Therefore, at the highest signal levels, the masking function for the off-frequency condition seems to remain nonlinear. Put another example regarding these results: new signal threshold = old signal threshold + 5dB (change in middle ear) - 10dB (change in effective masking) = old signal threshold - 5dB. This condition is like wearing an earplug in a noisy place.

Some programs to ameliorate the effects of noise on speech intelligibility, prescribe ear protective devices. Because earplugs attenuate equally the speech signals and the ambient noise passing through them at each frequency, the S/N at any frequency remains constant at the listener's eardrum. Accordingly, speech intelligibility should not be improved, because the speech signal will remain the same relative to the noise spectrum regardless of whether earplugs are worn. However, what happens in ears with normal hearing is that when the earplugs are worn in very intense noise (*e.g.*, 90 dB), speech intelligibility is improved because the speech and noise are reduced to a level where the ear is not "overloaded". Therefore, distortion is reduced and now speech can be discriminated better despite the noise (13). In some experiments, the degree of deterioration of hearing was greater when the pressure was increased than when it was decreased. However, in our study we did not find any significant effect of this event on noise thresholds in different pressure conditions (± 300 daPa).

Having discussed the facts which had been outlined through this study, the off-frequency masking at high levels is not linear because when you decrease the masker level by stiffening the ME, you will find that the signal threshold decreases by greater amount than decline in masker level.

Finally, aside from the nonlinearity in cochlear masking, changing the stiffness of the middle ear may not result in a frequency-independent attenuation. In other words, it will probably attenuate low frequencies more than high frequencies, which could also contribute towards the observed effect of a release from masking. This is because an increase in the stiffness of the middle ear will lead to an increase in the resonant frequency of the system, thereby possibly boosting higher frequencies while attenuating lower frequencies.

Recommendations and Limitations

The fact that thresholds decreased when we introduced a pressure difference could be interpreted in terms of reduced spread of masking associated with a lower effective masker level. However, the nonlinear growth of masking is usually found only for signal frequencies above the masker frequency, whereas you found a bigger reduction in masking for the low pass noise than for the high pass noise. A complicating factor is that the masker might have activated the middle ear reflex. The effects of this are hard to predict without knowing the details of cutoff-frequencies of the low pass and high pass noise. Therefore, using noise as a signal in this study makes it very hard to know which part of the noise (*e.g.* what frequency region) was responsible for determining the threshold, and in the future researches we should use pure tones as signal rather than low pass and high pass noises. In future studies, hearing thresholds assessments in different conditions of air pressure should be counter-balanced across subjects to avoid order bias. Moreover, it will be very helpful to conduct this experiment without the presence of the 226 Hz tone. This would be an important control condition to evaluate the effect of middle ear stiffness changes on sound transmission without the presentation of a masker.

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